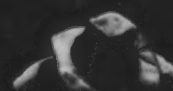


EXPLORE *in* MANITOBA

Report of
Activities
2001



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**Manitoba
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REPORT OF ACTIVITIES 2001

2001

This publication is available in large print, audiotape or braille on request.

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REPORT OF ACTIVITIES 2001



A message from the Minister:

Manitoba's mineral potential makes this province one of the most attractive places in the world to invest in exploration and mining. We offer many strategic advantages to the explorationist and mine developer. One of the most important is the solid geoscience information base needed to support a growing industry. Through the work of the department's geological survey, we continue to help define Manitoba's mineral potential and assist industry in the search for new discoveries.

The Report of Activities is a comprehensive summary of geoscience investigations conducted by the Manitoba Geological Survey in the past year. Collaborative projects with the federal government, Canadian and American universities, the mineral exploration industry and various geoscience organizations across Canada are also included. The report provides industry with the most current geoscience information available to help focus exploration strategies and assist with mineral investment decisions in the coming year.

The compilation of our comprehensive provincial geoscience database is due in large part to the dedication, expertise and hard work of survey staff. I am proud to note that Mark Fedikow, Chief Geologist for the Manitoba Geological Survey's Mineral Deposits Section, was awarded the 2001 Provincial Geologist's Medal for his outstanding contributions to geoscientific research. Mark is an internationally recognized leader in the development and application of multimedia geochemical surveys and exemplifies the expertise that exists within our own organization and in provincial geological surveys across Canada.

The Manitoba Geological Survey, together with the rest of the department, recognizes the mining industry as a key sector of Manitoba's economy. We are committed to supporting initiatives that ensure the growth of the industry and the long-term viability of mining communities in Manitoba. The release of this report at our annual Manitoba Mining and Minerals Convention puts some of our most current geoscience information

directly into the hands of existing stakeholders and new investors—the ideal forum to stimulate discussions and highlight opportunities. We also provide the entire report on our web site and have included a digital copy on CD-ROM in delegate bags to ensure that the latest on Manitoba geology is readily accessible to everyone.

I hope that the information in this report entices you to invest in one of Manitoba's natural advantages—our mineral wealth.

A handwritten signature in dark ink, appearing to read "M. Mihychuk".

Honourable MaryAnn Mihychuk
Minister of Industry, Trade and Mines

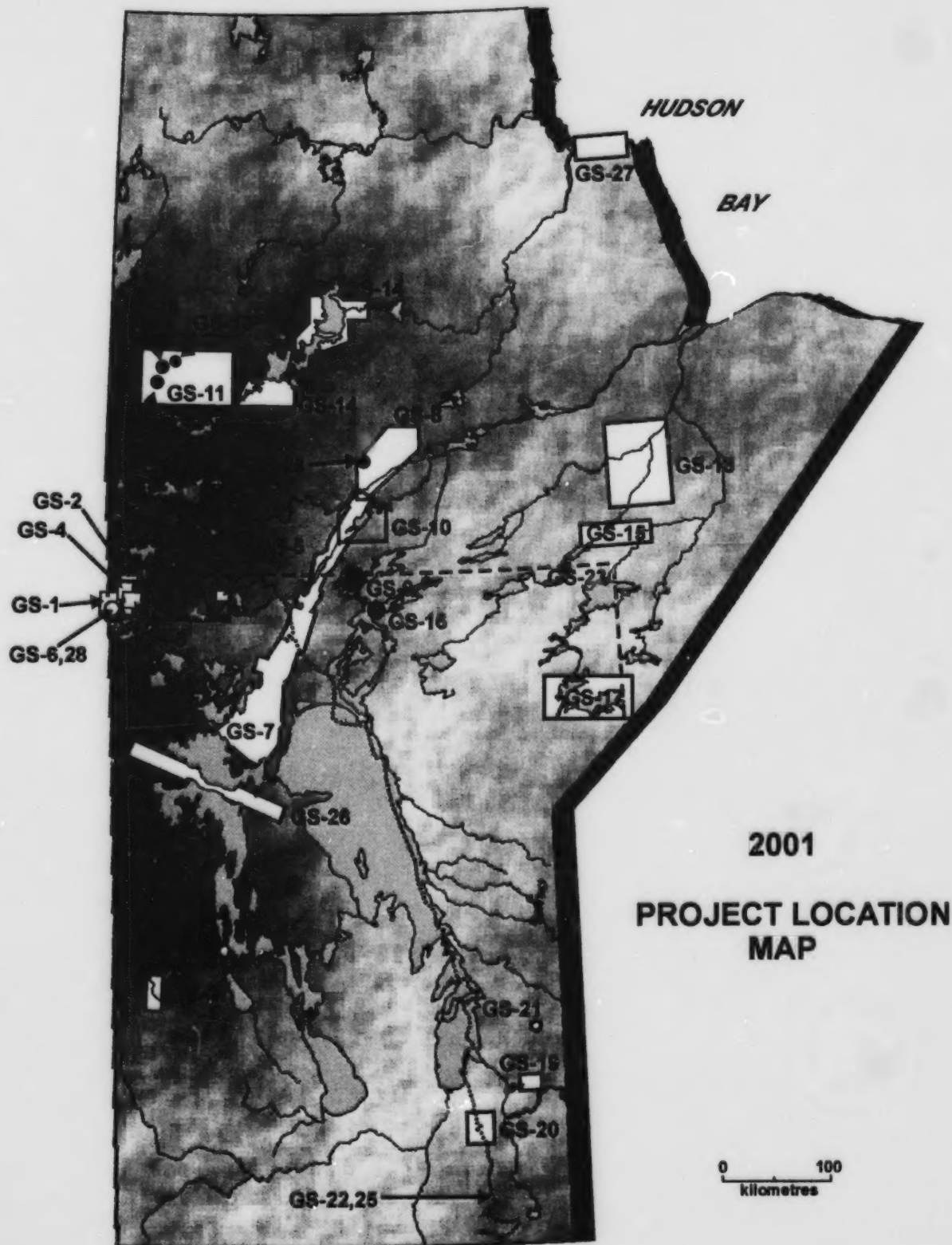


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INTRODUCTION

Geoscience activities in Manitoba this year reflect the completion of some major projects (e.g., Thompson Nickel Belt CAMIRO), the final year of other collaborative ventures (e.g., Western Superior NATMAP) and the start of new projects (e.g., Targeted Geoscience Initiative projects in Lynn Lake–Leaf Rapids and Flin Flon). Organizational changes included the filling of three technical management positions in October 2001. Alan Bailes (Chief Geologist, Precambrian Mapping Section), Ruth Bezys (Chief Geologist, Sedimentary and Industrial Minerals Section) and Mark Fedikow (Chief Geologist, Mineral Deposits Section) will work to ensure that the geoscience program in Manitoba is strong, responsive and relevant.

The 2001–2002 geoscience program reflects a balance between providing support to traditional mining camps, stimulating new exploration and development opportunities in frontier areas, and supporting land-use and development priorities in southern Manitoba. The program is reviewed annually by the Mineral Exploration Liaison Committee (MELC), composed of members of the Mining Association of Manitoba, the Manitoba Prospectors and Developers Association and the Manitoba–Saskatchewan Prospectors and Developers Association, as well as representatives from the University of Manitoba and the Geological Survey of Canada (GSC).

PARTNERSHIPS AND COLLABORATIVE PROJECTS

Partnerships or collaborative projects with external agencies and organizations form an increasing proportion of the Manitoba Geological Survey (MGS) geoscience program. Such partnerships make best use of combined funds and expertise, and result in high-quality, focused, effective programs. The partnered initiatives include contributions from the federal government, the mineral-exploration industry and several Canadian universities (Table 1). These partnerships are expected to add approximately \$1.9 million to geoscience programming in Manitoba for 2001–2002, representing significant leverage of the MGS geoscience budget. In recognition of the importance of partnerships, Tim Corkery will assume responsibility for co-ordinating, seeking out and fostering such relationships.

GEOSCIENCE PROGRAM

The MGS geoscience program is designed with a regional emphasis, focusing on those areas most in need of new or updated geological information. In 2001–2002, approximately 31% of the total project-related operating budget was directed toward studies in the northern Superior Province, primarily for programs in support of diamond-related exploration. Approximately 48% of the project-related operating budget was directed toward projects within traditional mining camps: Flin Flon Belt, Lynn Lake Belt, Thompson Nickel Belt and southeastern Manitoba. The remaining 21% supported Quaternary, aggregate, industrial minerals and land-use planning in the south-central part of the province, as well as province-wide projects.

Federal-provincial co-operation and co-ordination of geoscience projects continued with the Government of Canada's \$15 million, three-year Targeted Geoscience Initiative (TGI). The Geological Survey of Canada (GSC) is involved in two projects located in Manitoba and adjoining portions of Saskatchewan. Funding from GSC through the TGI is matched by funding and in-kind contributions by MGS and the Saskatchewan Geological Survey (SGS). The mapping projects will significantly increase understanding of the geology and mineral deposits in the Lynn Lake–Leaf Rapids and Flin Flon regions, where there is significant potential for the discovery of new base- and precious-metal deposits.

FLIN FLON–SNOW LAKE

Geoscience investigations in the Flin Flon Belt have been thematic in nature following completion of the regional NATMAP Shield Margin project. In 2001, work was concentrated on TGI projects near Flin Flon, mineral-deposit studies at Snow Lake and a regional mapping project in the Naosap–Wabishkok area.

Nine new projects have been initiated under the Flin Flon TGI. These projects are designed to increase understanding of the volcanic and hydrothermal events influencing the setting of volcanogenic massive sulphide (VMS) deposits in the central Flin Flon Belt. This study brings together geoscientists from the GSC, MGS, SGS, Laurentian University and the University of Manitoba to collaborate with local exploration geologists from Hudson Bay Exploration and Development Co. Ltd., Aur Resources Inc. and M'Ore Resources. The Flin Flon TGI involves separate but integrated subprojects spanning the Manitoba–Saskatchewan border, including alteration-related studies, trace-element geochemistry of VMS deposits, a cross-border geological compilation of the Flin Flon area, and a facies study of the volcanoclastic host rocks to the Flin Flon, Triple 7 and Callinan deposits. Detailed (1:500 scale) mapping of volcanological and structural features along the Flin Flon 'mine horizon' has been initiated through collaboration of geologists from MGS, SGS and Laurentian University.

Table 1: Collaborative geoscience projects in Manitoba, 2001-2002.

PROJECT AND PARTNERS	CURRENT STATUS (2001)
Flin Flon Belt:	
Flin Flon TGI (GSC, SGS, HBED, Aur Resources Inc., M'Ore Resources, Laurentian U.)	Second year of a three-year project; fieldwork at Flin Flon and Baker-Patton; three M.Sc. and two B.Sc. theses in progress; see GS-1 and Preliminary Maps 2001F-1 and 2001F-2
Flin Flon Belt geochronology (HBED)	Data collection in progress; preliminary results released in 2001 GAC abstract
Snow Lake gold studies (TVX Gold Inc., U. of Manitoba)	Fifth year of ongoing project; two M.Sc. theses completed; see GS-5
Snow Lake base-metal vectors (Callinan Mines Ltd., W. Bruce Dunlop Ltd.)	Third year of ongoing project; data collection dependent upon availability of drill core
PGEs in the Flin Flon Belt (Fort Knox Gold Resources Inc.)	Geological mapping, sampling; geochemical investigations ongoing; see GS-4
Lynn Lake-Leaf Rapids:	
Lynn Lake gold studies (U. of New Brunswick, Laurentian U., U. of Manitoba, NSERC)	Second year of a three-year project; part of Manitoba's contribution to the Lynn Lake-Leaf Rapids TGI; one Ph.D. and two M.Sc. theses in progress; see GS-11, -12 and -13
Superior Boundary Zone-Reindeer Zone transition (U. of Alberta)	New project; see GS-8
Lynn Lake-Leaf Rapids TGI (GSC, HBED, Aur Resources Inc.)	First year of a two-year project; fieldwork in the Rusty Lake belt and Southern Indian Lake; see GS-14
Lynn Lake-Leaf Rapids soil gas hydrocarbons (SGH), specifically centred on Ruttan Cu-Zn deposit (HBED, CAMIRO, Activation Laboratories Ltd.)	First year of a two-year project; fieldwork in the Ruttan area
Lynn Lake multimedia geochemistry; development of surficial-environment exploration geochemistry technique (Strider Resources Ltd., International Curator Ltd., Rare Earth Metals)	First year of a two-year project; fieldwork in the Lynn Lake Belt
Thompson Nickel Belt-Superior Boundary Zone:	
Thompson Nickel Belt CAMIRO 97E-02 (Inco Ltd., Falconbridge Ltd., HBED, Billiton Metals Canada Inc., Western Mining International Ltd., Laurentian U., U. of Manitoba, U. de Québec à Montréal, U. of Alberta, U. of Sask., GSC, NSERC)	Completed; final report, workshop and field trip for sponsors held in August 2001; results to be presented at a proposed special session during the 2002 Manitoba Mines and Minerals Convention
Thompson Nickel Belt compilation (Inco Ltd., Falconbridge Ltd., HBED)	In progress; preliminary maps for the exposed and sub-Phanerozoic portions of the TNB were released in June 2001; see GS-7
Fox River Belt geology and metallogeny (Falconbridge Ltd.)	In progress; see Preliminary Map 2001S-1
Northern Superior:	
Western Superior NATMAP (OGS, GSC, McGill U., U. of Alberta, ROM, U. of Maryland, LITHOPROBE, NSERC)	Final year of project (1996-2002)
Operation Superior multimedia and kimberlite indicator-mineral surveys (De Beers Canada Corp.)	Sixth year of project (1996-2001); see GS-15
Operation Superior geological, geochemical and geophysical data integration (GSC)	Second year of project
Cross Lake structural studies (U. of Maryland, U. of Waterloo)	Final year of an M.Sc. thesis on Pipestone Lake area (see Preliminary Map 2001S-2); first year of a Ph.D. thesis on the Central Cross Lake Shear Zone (see GS-16)
Island Lake supracrustal studies (U. of Waterloo)	Second year of a structure-geochronology M.Sc. thesis; see GS-17
Southeastern Manitoba:	
Bird River Sill (Canmine Resources Corp.)	Core relogging and geochemistry; petrology and thin section studies ongoing; see GS-19
Southeastern Manitoba digital compilation (GSC)	Completed; joint GSC-MGS release, November 2001
Western Superior NATMAP (OGS, GSC, McGill U., LITHOPROBE, NSERC)	Final year of project (1996-2002); one M.Sc. thesis completed at Wallace Lake
Precambrian monadnocks apatite fission track dating (GSC-C, U. of Melbourne)	Ongoing; Ph.D. thesis; see GS-20

Table 1: Collaborative geoscience projects in Manitoba, 2001-2002. (continued)

PROJECT AND PARTNERS	CURRENT STATUS (2001)
Southern Manitoba:	
Hydrogeology (GSC, WRB, U. of Manitoba)	Final year of project (1996-2002); four M.Sc. theses, one Ph.D. thesis and two post-docs
Greater Winnipeg NATMAP (GSC, universities)	Final year of project (1997-2002); two M.Sc. theses, two Ph.D. theses and two post-docs; see GS-23
Climate change in southern Manitoba during the last millennium (GSC, CCAF)	Completed; final report submitted in June 2001
Paleofloods of the Red River (GSC, IJC, RRFPF)	Third year of project (1999-2003); results presented at scientific conference in Davos, Switzerland (September 2001)
Geochemical Pathways Study (bedrock to vegetation; U. of Manitoba)	M.Sc. thesis
Prairie-type mineralization (U. of Manitoba, U. de Québec à Montréal, U. of Alberta, U. of Brussels, GSC-C)	Ongoing
Black Shale Study (GSC)	Ongoing
Manitoba:	
Aggregate inventory (T&GS)	Ongoing; MGS provides field data to T&GS; T&GS processes aggregate samples; see GS-27

Regional mapping in the Wabishkok Lake area has documented a volcanic section dominated by pillowed basalt, derived gneiss and intercalated gabbro, interpreted as arc-type rocks. Most occurrences of surficial mineralization occur within basalt, but one of the most significant economic prospects is associated with felsic volcanic rocks. This lithologically and structurally complex portion of the Flin Flon Belt has not been mapped since the 1950s.

The Josland Lake sill, a differentiated mafic body northwest of Reed Lake, has yielded a U-Pb zircon age of 1886 ± 3 Ma. The sill, 24 km long and up to 2 km thick, belongs to a larger suite that has a unique geochemical fingerprint throughout its regional extent from Snow Lake and Reed Lake to the south flank of the Kisseynew Domain. The sills are interpreted to represent a major igneous province, including the 1881 Ma Mikanagan Lake sill at Flin Flon. Elevated platinum-group element (PGE) concentrations and gold deposits in the sills make them significant exploration targets.

The recently discovered McBratney Lake PGE occurrence, located 7 km east of Flin Flon, highlights the mineral potential for 'contact-type' PGE mineralization associated with the physical and chemical interaction between a gabbroic magma and sulphide-bearing mafic volcanogenic host rocks. The McBratney Lake PGE discovery is significant because of the exceptionally high PGE tenor and significant potential for similar mineralization at gabbro-basalt contacts in the region.

Other activities related to mineral deposits in the Flin Flon Belt included work toward completion of Baker-Patton project reports and maps, ongoing studies of the New Britannia mine, and utilization of rare-earth elements (REE) as exploration tools for precious- and base-metal deposits.

THOMPSON NICKEL BELT

The Manitoba Geological Survey has initiated several new studies to generate geological data and interpretations directly applicable to nickel exploration in the Thompson Nickel Belt (TNB). These studies will also constrain the tectonic evolution of the western margin of the Superior Province and support the ongoing geological documentation of the northern Superior Province and the Superior Boundary Zone.

The MGS and industry partners, Inco Ltd., Falconbridge Ltd. and Hudson Bay Exploration and Development Co. Ltd., have been involved in a multiyear collaborative program designed to create a new compilation map of the TNB. A preliminary version, published in June 2001, includes a set of fifteen maps that cover an area from Moak Lake (northeast of Thompson) to Bracken Lake (north of Grand Rapids). These maps represent preliminary results of the compilation effort and will ultimately be superseded by final maps. During the summer of 2001, diamond-drill core from the southern part of the exposed TNB was examined in Wabowden. Data obtained will be incorporated in the final version of the TNB compilation map.

In the spring of 1997, the Thompson Nickel Belt CAMIRO project, an industry-supported project in support of exploration, was launched in the TNB. This four-year (1997-2001) study, with an industry-NSERC budget of approximately \$800 000, is administered by the Canadian Mining Industry Research Organization (CAMIRO) and includes researchers from MGS, GSC, University of Manitoba, Laurentian University, University of Alberta, Université de Québec à Montréal and University of Saskatchewan. The project currently has five industry sponsors (Inco Ltd., Falconbridge Ltd., Hudson Bay Exploration and Development Co. Ltd., Billiton Metals Canada Inc. and Western Mining International Ltd.). The Thompson Nickel Belt CAMIRO project wrapped up with a sponsors' meeting and field trip in August 2001.

SUPERIOR BOUNDARY ZONE

An MGS- and NSERC-supported, integrated mapping, geochemistry and isotopic study of the western Superior craton margin northeast of Thompson has indicated that a re-interpretation is required of the location and nature of the boundary zone between the Archean Superior Province and the Paleoproterozoic Trans-Hudson Orogen. Previous work found evidence for ancient (pre-3.7 Ga) crust in the Assean Lake area of the western Superior Province.

A new project was started to document the geological relations and isotopic ages of rocks north of Thompson, along the complex boundary zone between the northwestern Superior craton and the Trans-Hudson Orogen. In 2001, work proceeded on a 60 km transect from Thompson to Pearson Lake. Samples were collected in this poorly accessible area for a variety of studies, including Sm-Nd isotope systematics and U-Pb age determinations, to be conducted at the University of Alberta. Relogging and sampling of company-owned drill core from an area northwest of Mystery Lake was carried out with the co-operation and help of Inco Ltd. and Nuinsco Resources Ltd.

A study along the east margin of the TNB was undertaken in order to characterize the metamorphic transition from granulite of the Archean Pikwitonei Granulite Domain to amphibolite-grade Paleoproterozoic gneiss of the TNB.

LYNN LAKE-LEAF RAPIDS

A TGI project began in the Lynn Lake-Leaf Rapids area, as a co-operative effort between the GSC, MGS, Hudson Bay Exploration and Development Co. Ltd. and Aur Resources Inc. The MGS component of this TGI project includes mineral-deposit-scale studies, structural mapping of mineralized shear zones and targeted geochemical surveys to aid mineral exploration. The GSC component of the project encompasses field studies in a broad area, regional tectonics and geochronological studies.

The MGS began an integrated study to better understand the gold and base-metal potential of the Lynn Lake Belt in 1999. Two thesis projects were begun in 2000 and continued in 2001. A Ph.D. study of the Agassiz Metallotect involves structural, stratigraphic, mineralogical and geochemical investigations into the genesis of gold mineralization in one of the more significant, regional, gold-bearing structures in the Lynn Lake Belt. The second project, an M.Sc. study concentrating on the BT, Bonanza and McBride deposits, involves structural, mineralogical and geochemical investigations into the genesis of gold mineralization associated with the Johnson Shear Zone. These new studies were augmented by an M.Sc. study at the University of Manitoba, utilizing existing and new digital datasets in the Lynn Lake area to develop a predictive tool for gold exploration.

Continuing structural analysis of the southern Lynn Lake Belt has delineated six generations of ductile to brittle-ductile fabrics. An intense D_2 transposition-shearing deformation overprints the earliest geometry, producing the east-west geometry of the greenstone belt. Gold mineralization is hosted by mafic and felsic metavolcanic rocks affected by the shear zones. The delineation of these shear zones within the greenstone belt significantly increases the amount of underexplored gold-prospective stratigraphy in the Lynn Lake Belt beyond the Johnson Shear Zone, and is highlighted by the identification of several alteration zones similar to those associated with known gold mineralization.

Deformation structures along the south margin of the Johnson Shear Zone in the Pool Lake-Boiley Lake area southwest of Lynn Lake were subdivided on the basis of overprinting relationships into seven generations. The D_2 shear zones in the Pool Lake area are interpreted to be second- or third-order splay flanking the Johnson Shear Zone and, as such, are highly prospective exploration targets. Splay structures tend to be developed over wide areas (>5 km) along the flanks of the primary shear zone, indicating that most of the southern Lynn Lake Belt should possess excellent exploration potential for mesothermal, shear-hosted gold deposits.

Detailed geological mapping of the western portion of the Agassiz Metaltect near Lynn Lake has documented the stratigraphic constituents of the metaltect and enclosing rocks. The host lithology of the MacLellan gold deposit and other subeconomic deposits is strongly sheared, altered, high-Mg-Ni-Cr basalt (picrite). The picrite was locally intensely sheared during D_2 , with attendant gold mineralization and alteration. The textural relationships between deformation structures, and the ore and gangue mineral assemblages suggest an epigenetic, synshear origin for the gold mineralization in the MacLellan deposit.

The Geological Survey of Canada began the first field season of a TGI project aimed at providing a regional tectono-stratigraphic context for supracrustal and plutonic rocks along a transect extending from the north flank of the Kiseeynew Domain, through the Lynn Lake, Leaf Rapids and Southern Indian domains, to the south margin of the Chipewyan Batholith. This transect is similar in nature to the recently completed transect along the northwestern flank of the Reindeer Zone in Saskatchewan, which led to the discovery of new exploration targets and renewed economic interest in the region. The 2001 field program included a re-evaluation of the lithotectonic framework along a transect from the northwestern margin of the Rusty Lake belt to the Partridge Lake belt, as well as a companion study on the mineral potential of the Rusty Lake belt. Preliminary results show that most of the lithotectonic entities defined along Reindeer Lake in Saskatchewan can be traced into Manitoba. Volcanic and plutonic rocks were sampled for geochemical analysis, U-Pb dating and Sm-Nd tracer-isotope studies. Major sedimentary assemblages were also sampled for U-Pb sensitive high-resolution ion microprobe (SHRIMP) dating of detrital zircons.

NORTHERN SUPERIOR PROVINCE

Manitoba's five-year 'Operation Superior' multimedia geochemical survey began in 1995 and completed its final year of data collection in 2000, but the program's success led to a continuation of the survey in the northern Knee Lake region in 2001. The objectives of this and related initiatives in the northern Superior Province were to 1) identify regional exploration targets through new geochemical and kimberlite indicator-mineral surveys and compilations of geophysical data derived from assessment files; and 2) provide the geological framework for mineral exploration through regional mapping and thematic studies. This program is linked to the larger Western Superior NATMAP project that is focused on defining the crustal evolution and tectonic assembly of the Superior Province west of Lake Nipissing. New 1:250 000 scale bedrock geology compilation maps will be produced in 2001–2002 as contributions to the Western Superior NATMAP project, which has entered its last operating year. Regional mapping conducted under the auspices of the Western Superior NATMAP was limited in 2001, with emphasis placed instead on evaluation and consolidation of data collected during the project.

During Operation Superior, helicopter-supported, multimedia geochemical surveys targeted greenstone belts throughout the northern Superior Province. In 2001, rock, till, b-horizon soil, humus and vegetation samples were collected for multi-element geochemical analysis from 157 sites in the area west, north and east of the northern half of the Knee Lake greenstone belt. The sampling included 150 bulk samples (20–25 kg) of till and beach sand collected for kimberlite indicator-mineral identification and analysis.

A new project was undertaken this year to outline the Quaternary stratigraphy and determine the provenance of tills in the northern Superior Province and adjacent Hudson Bay Lowland, in support of diamond exploration. Investigations include a combination of pebble analysis, carbonate analysis, matrix geochemistry, textural analysis, kimberlite indicator-mineral analysis and pebble-fabric analysis. A total of 69 till and 2 alluvial-sand samples were collected from seven sections exposed in river cuts.

Mapping by an M.Sc. student from Waterloo University in the Island Lake greenstone belt has documented the volcanic and volcanogenic sedimentary rocks of the Hayes River Group and the sedimentary rocks of the Island Lake Group. Field mapping and geochronological work in 2001 have helped to define lithologically and chronologically distinct structural panels of Hayes River Group rocks.

A structural study at the University of Maryland, partially sponsored by the MGS, was conducted in the central and southern parts of the Cross Lake greenstone belt, concentrating on the east-southeast-trending high-strain zone. This Ph.D. project will contribute to the growing understanding of Archean tectonics in the northern Superior Province.

SOUTHEASTERN MANITOBA

Geoscience activities in southeastern Manitoba were extremely varied in 2001 and include regional compilations, PGE-related investigations, research into post-Precambrian tectonics and a study on the phytoremediation of mine tailings.

The GSC completed a digital compilation of geological, geochemical and geophysical data sets for southeastern Manitoba, with datasets assembled and provided by both the MGS and GSC. The aim of this collaborative project was to produce a CD-ROM containing all available digital data to aid mineral-exploration activities.

The MGS conducted studies supportive of PGE exploration in the Bird River sill in 2001. Three PGE-bearing stratabound layers, two of them intimately associated with chromitite layers, were defined on the Chrome property in previous studies. A sulphide-bearing layer associated with chromitite layers was defined this summer on the Page property. This sulphide-bearing layer is a conspicuous marker horizon containing disrupted chromitite layers and chromitite 'pebbles', consistent with an at least periodically dynamic magma chamber and highly significant for guiding the search of PGE-bearing layers.

Precambrian monadnocks rising 5 to 20 m above the surrounding prairie level north of Beausejour were visited to collect samples for apatite fission track thermochronology that should provide clues to the origin, tectonics and hydrocarbon-metallic-mineral generation of the Williston Basin.

A new project to determine the potential for phytoremediation of mine tailings and production of bio-ores, through the identification of plant species that can accumulate heavy metals, was initiated in 2000 at the Central Manitoba gold mine site in southeastern Manitoba. Preliminary results have shown that several plant species were able to survive and grow for two growing seasons on two of the three selected sites without any remediation of the soil. Preliminary results from analyses of plants growing on tailings for one growing season indicate substantial enrichment of Au in pine and spruce seedlings, and enrichment of Zn in willow.

SOUTH-CENTRAL MANITOBA

Phanerozoic Studies

The Capital Region Study involves an investigation of the crushed-stone and mineral potential in and around the City of Winnipeg. Preliminary maps for the northern portion of the Capital Region Study, released in printed form in 1999, will have

significant utility for land-use planning in surrounding municipalities. The mapping of the southern portion of the area has been completed and the maps and report for the entire Capital Region are in the final editing stage.

Stratigraphic investigations and drilling programs were carried out for various projects. The Manitoba Stratigraphic Database (MSD) continues to be updated. It now contains 5619 stratigraphic, mineral-exploration, oil-and-gas and other wells, of which 4340 have formation tops. One corehole was drilled at Denbeigh Point (Lake Winnipegosis) to intersect the Precambrian; three coreholes were drilled in the Wekusko Lake-Iskwassum Lake area to test metallic veining in the Red River Formation; and one corehole was drilled at Steeprock River bridge to intersect mineralization within Mesozoic infill. A total of 326.6 m of drilling was conducted this year.

Accessing the mineral potential of Phanerozoic rocks and underlying Precambrian basement is an important facet of MGS work. In June and July 2001, a gravity and magnetic survey was completed along The Pas Moraine. The purpose of this survey was to investigate the gravity and magnetic field of the Superior Boundary Zone in this region, and to obtain more information on the possible southern extension of the Thompson Nickel Belt.

Quaternary Studies

In addition to the multimedia and diamond-indicator studies in the northern Superior Province, two Quaternary research topics are being investigated in Manitoba. The first project is studying the influence of recent geological and climatological processes on flood frequency in the Red River valley, while the second deals with the compilation of digital datasets in support of a three-dimensional (3-D) digital geological model for southern Manitoba. Both projects represent collaborative efforts with the Geological Survey of Canada.

Research on the long-term sustainability of the fresh groundwater resource in southern and central Manitoba is addressing the protection of recharge and ensuring that extraction does not lead to unacceptable lateral migration of saline waters. Three-dimensional (3-D) modelling is a key element of this strategy, with applications ranging from basic science to groundwater-flow modelling and livestock management. The intention of this study is to construct a 3-D geological model for the Phanerozoic terrane of southern Manitoba, south of latitude 55°N and west of longitude 95°W. The Phanerozoic sequence, comprising Quaternary sediments and Phanerozoic sedimentary rocks, down to and including the Precambrian surface will be modelled, requiring the acquisition of all readily available, nonconfidential, drillhole databases that can be utilized in a geographic information system (GIS) environment.

AGGREGATE

Aggregate-resource inventories are being updated for a number of Rural Municipalities in southern Manitoba. In the Capital Region area, the long-term objective is to update 1:100 000 scale aggregate resource maps. In 2001, assessment of aggregate resources was carried out in a number of candidate sites proposed under the Protected Areas Initiative. Aggregate inventories were carried out in the Churchill area, the Rural Municipality of Grandview and several crown-land parcels (Areas of Special Interest) in southern Manitoba. Approximately 300 sites were visited and 100 samples taken. This year, some of the new pits, quarries and access roads were mapped digitally, using a global-positioning system (GPS) unit.

LAND USE

The Manitoba Geological Survey conducts a number of activities related to sound land-use management: 1) provision of mineral-resource assessments in candidate sites under the Protected Areas Initiative; 2) identification of potential geological hazards (shoreline erosion, neotectonics, landslides); 3) review of land-use planning submissions; 4) examination of applications for surface use of crown land to ensure that access to mineral occurrences is not adversely affected; and 5) collaborative programs with Manitoba Conservation, Manitoba Hydro and the GSC to evaluate geological hazards and potential impacts on development.

GEOSCIENCE INFORMATION

The Geoscience Information Services Section has worked extensively on digital conversion of both bedrock and surficial geology maps. Geographic Information System (GIS) and data-management support has been given to the Western Superior NATMAP project, Flin Flon TGI and compilation of digital geological data for southeastern Manitoba. New presentations were developed for the Internet map server system on the departmental Web site.

REGIONAL OFFICES

The Flin Flon office continues to provide assistance to the mineral-exploration and mining communities in the Flin Flon-Snow Lake region, including recording new mineral claims, maintaining an up-to-date library of provincial claim and land-status maps, dealing with claim-status inquiries, accepting assessment-work submissions, and maintaining an up-to-date core-library database. The present staff of two geologists will be augmented by a Mining Claims Inspector, to be transferred

from The Pas to Flin Flon. An inventory is in preparation of the core repository at the Centennial mine site and all core piles have been reorganized and stabilized. The mine-documentation project is proceeding with the addition of new ore samples from a number of now-closed mines and the establishment of a database for the core repository at the Stall Lake mine near Snow Lake.

Staff in the Thompson regional office respond to a range of inquiries, including regional geology, potential of mineral properties and mineral identifications. The Thompson office provides Mining Recording services to the community, including data on the status and registration of claims, access to and sales of maps and reports, and access to electronic databases. In July 2001, Scott Anderson joined the MGS and is currently working out of the Thompson office. Scott brings considerable skills and experience to mineral-deposit and structural studies in the Lynn Lake Belt and in southeastern Manitoba.

ACKNOWLEDGMENTS

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Galley, A.G. and Bailes, A.H. 2001: Flin Flon Targeted Geoscience Initiative; in Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 9-17.



SUMMARY

Nine new projects have been initiated under the auspices of the Flin Flon Targeted Geoscience Initiative (TGI). These projects are designed to increase understanding of the volcanic and hydrothermal events influencing the setting of volcanogenic massive sulphide (VMS) deposits in the central Paleoproterozoic Flin Flon Belt. The primary objective of the project is to provide a sophisticated geological context that will permit mining and exploration companies in the area to undertake cost effective and, hopefully, successful exploration programs. This cross-border study brings together geoscientists from the Geological Survey of Canada (GSC), Manitoba Geological Survey (MGS), Saskatchewan Geological Survey (SGS), Laurentian University (LU) and the University of Manitoba (U of M) to collaborate with local exploration geologists from Hudson Bay Exploration and Development Co. Ltd. (HBED), Hudson Bay Mining and Smelting Co. Ltd. (HBMS), Aur Resources Inc. and M'ore Exploration Services Ltd.

INTRODUCTION

The Flin Flon Targeted Geoscience Initiative (TGI) is part of a \$15 million, three-year federal initiative designed to develop new criteria to assist exploration and mining companies. The purpose of the TGI projects is to increase ore reserves, thereby stabilizing the economies of northern mining communities. Specific projects were selected through consultation with provincial and territorial governments and adjudication by industry representatives. Funding for TGI projects is provided jointly by the federal and provincial governments.

The Flin Flon TGI was initiated in the spring of 2000 with a \$450 000 budget, which includes both operational and salary costs for the federal and provincial components of the project. The objectives of the Flin Flon TGI are to

- increase understanding of the volcanic and hydrothermal history of the central Paleoproterozoic Flin Flon volcanic belt;
- determine how these factors influenced the formation of contained VMS deposits; and
- assist the development of exploration strategies to support the discovery of new VMS deposits.

To ensure that the project objectives and components were recognized, understood and approved by local industry interests, an open meeting was held in Flin Flon during October 2000 to present the project outline and to discuss any concerns or additions that were tabled by the participants. This meeting was held in conjunction with an oral presentation of the aims and objectives of the program.

The Flin Flon TGI involves nine separate but integrated subprojects (Fig. GS-1-1) that straddle the Manitoba-Saskatchewan border and include most of the major VMS-hosting structural domains. The subprojects include four large-scale studies:

- delineation of oxygen-isotope patterns for regional-scale VMS-related hydrothermal systems
- trace-element research of all known VMS deposits and major sulphide occurrences
- a regional alteration study of the 'Bear Lake volcano'
- a 1:10 000 scale cross-border geological compilation of the Flin Flon area

In addition three detailed studies have been undertaken (Fig. GS-1-2):

- an alteration study of the Baker-Patton Rhyolite Complex
- a combination of detailed and large-scale hanging-wall studies of the Flin Flon VMS horizon
- a facies study of the volcanoclastic host strata to the Flin Flon-Triple 7 and Callinan deposits, which includes 1:500 scale mapping of volcanological and structural features along the Flin Flon 'mine horizon'

REGIONAL SUBPROJECTS

Oxygen-Isotope Mapping of VMS Hydrothermal Systems (Bruce Taylor [GSC] and Adrian Trimbal [GSC])

The purpose of this subproject is to generate domain-scale maps showing variations in oxygen-isotope values for volcanic and subvolcanic units associated with known or potential VMS mineralization. Taylor (in press) and Cathles (1993) demonstrated that oxygen isotopes are a sensitive tool in outlining areas of volcanic and subvolcanic rocks affected by subseafloor hydrothermal alteration. Furthermore, they demonstrated that anomalous isotope values, as defined by variations in $^{18}\text{O}/^{16}\text{O}$ normalized to modern seawater ($\delta^{18}\text{O}$) can assist in determining both high- and low-temperature parts of the hydrothermal

¹ Geological Survey of Canada, 601 Booth St., Ottawa, Ontario K1A 0E8

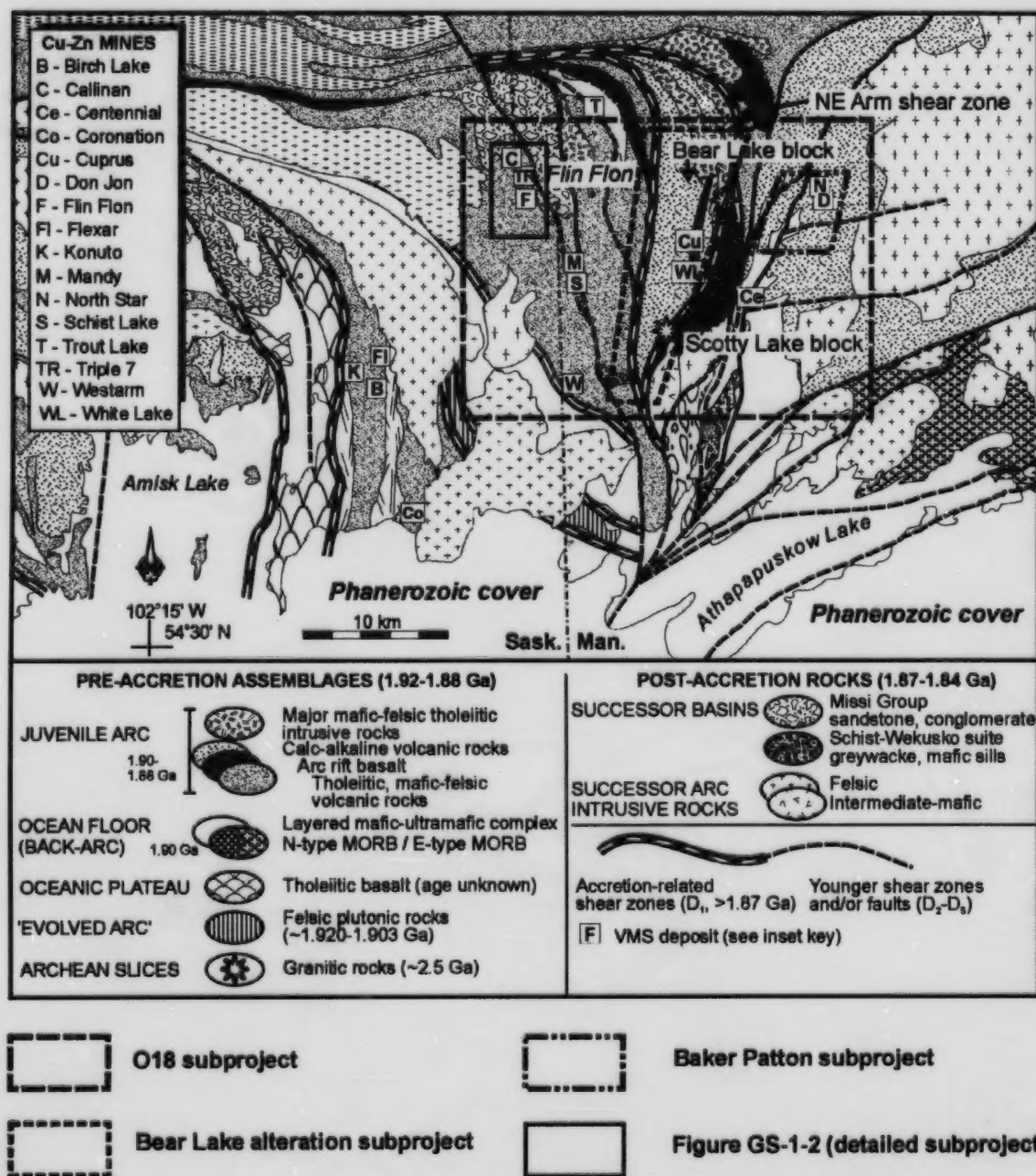


Figure GS-1-1: Tectonic-assemblage map of the central portion of the Flin Flon Belt (after Lucas et al., 1996) showing the location of regional-scale Flin Flon TGI subprojects.

system, which commonly bracket the potential VMS horizon.

Archived samples from MGS, as well as samples collected during other ongoing Flin Flon TGI subprojects, will be analyzed at the GSC. They will be used to develop oxygen-isotope maps at scales from 1:5 000 to 1:10 000, with the objective of delineating the size and nature of the hydrothermal systems associated with VMS deposits in the Flin Flon, Bear Lake and Baker-Patton domains (Fig. GS-1-1).

Trace-Element Signatures of Flin Flon VMS Deposits (Ian Jonasson [GSC], Doreen Ames [GSC] and Tom Heine [MGS])

An interesting aspect of current metallogenic studies is profiling Canadian VMS deposits through their trace- and rare-earth-element signatures. These signatures are considered to be a function of 1) the nature of the hydrothermal fluid; and

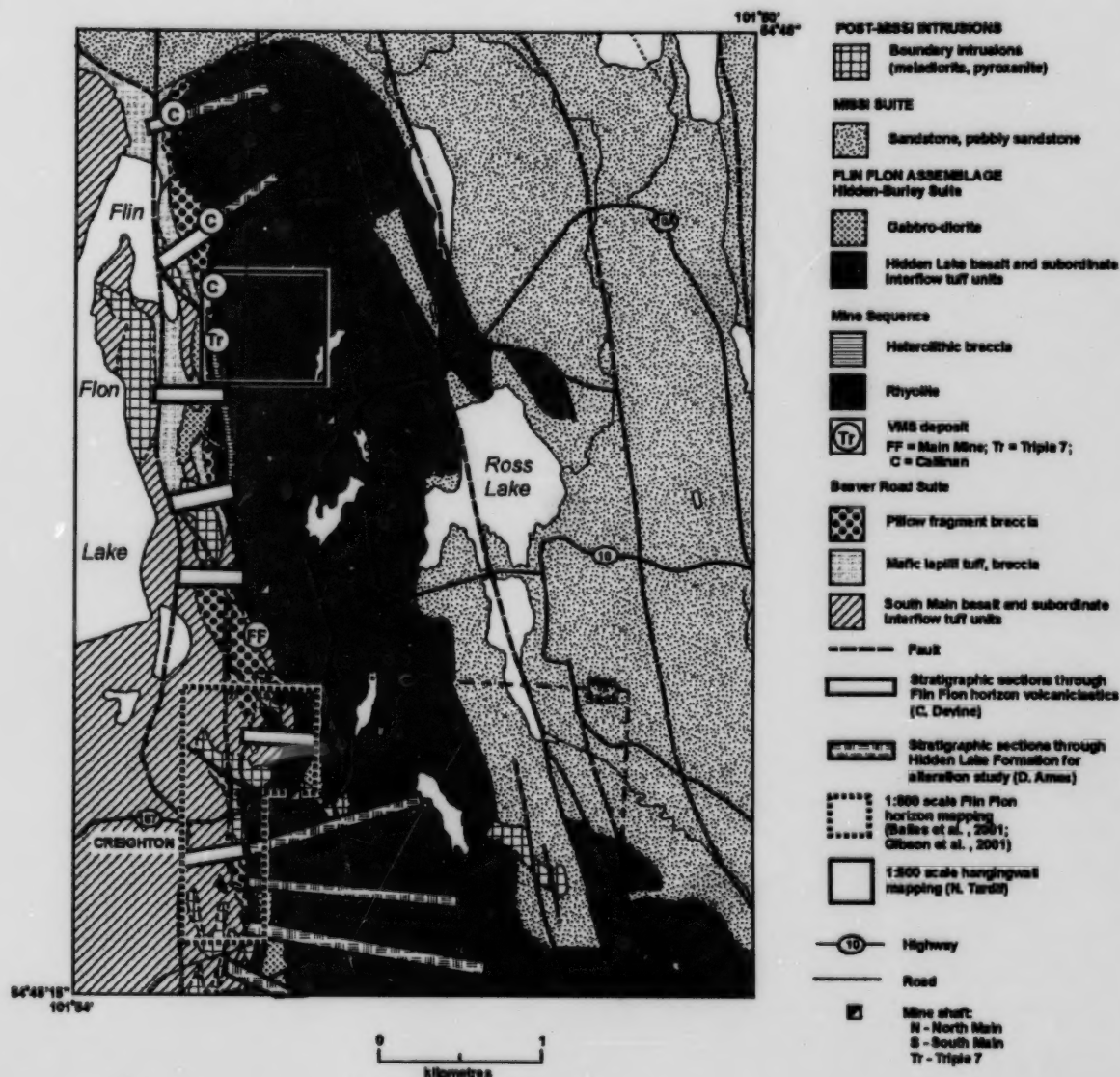


Figure GS-1-2: Simplified geology of the Flin Flon-Creighton area (after Syme et al., 1996), showing the location of subprojects in the immediate area of the Flin Flon-Triple 7-Callinan mine horizon.

2) the chemistry of the footwall strata, which supply metals and other elements to the hydrothermal fluid. Since the chemistry of these footwall rocks can be unique to the particular tectonic environment in which the VMS deposits were formed, it follows that VMS trace- and rare-earth-element signatures should also be unique and reflect this tectonic setting. The Flin Flon belt, with its wide range of VMS-hosting tectonic environments (Syme and Bailes, 1993; Lucas et al., 1996), is an ideal area in which to undertake an examination of the relationship of VMS trace-element signatures to their tectonic environment.

Trace- and rare-earth element-signatures of VMS deposits also have applications as exploration vectors, since sulphide minerals intercepted during drill programs or through prospecting can be analyzed, and their signatures compared to the geochemical archive developed during the Flin Flon TGI. This will assist companies in determining the nature of the intersected sulphide horizons, and possibly their potential with respect to metal ratios.

More than 300 samples from 14 VMS deposits and major sulphide occurrences have been collected and processed for geochemical analysis, with additional samples and deposits slated for collection and analysis in 2002. To date, only whole-rock analysis has been completed, but sulphide separates (pyrite, sphalerite, pyrrhotite and chalcopyrite) will be available for future analysis. Samples being analyzed are from GSC archives, HBED and the first two years of the project. In addition to analysis, samples are being slabbed, polished and photographed. The photographs will become part of a digital Flin Flon TGI datafile, and the slabs will be available for permanent display at a still-to-be-determined venue in Flin Flon.

Bear Lake Alteration Study (Alan Galley [GSC] and Alan Bailes [MGS])

The study of the Flin Flon volcanic assemblage by Bailes and Syme (1989) showed the fault-bounded Bear Lake structural domain to contain part of a flow-dominated basaltic andesite volcanic edifice that is topped to the east by a cauldron complex hosting the Cuprus and White Lake VMS deposits (Fig. GS-1-1). A large, epidote-rich alteration zone, affecting more than 40% of the volcanic stratigraphy in the Bear Lake structural domain (Bailes and Syme, 1989), is the target of this study. This alteration type commonly defines higher temperature parts of seafloor alteration systems that are in close spatial association with subvolcanic sills and feeder dyke swarms (Gibson and Watkinson, 1990; Galley, 1993; Galley and Koski, 1999). If this large area of epidote-rich alteration was produced by a high-temperature hydrothermal system, this implies that much larger quantities of metals were mobilized than those sequestered within the known and mined Cuprus and White Lake deposits of the Bear Lake area. The purpose of this project is to increase understanding of the Bear Lake alteration system and to evaluate its potential to have more associated sulphide mineralization than has currently been identified.

Surface cross-sections every 500 to 1000 m through the exposed volcanic stratigraphy are documenting alteration morphologies and mineralogical variations, and relating these features to changes in volcanic-flow facies and abundance of synvolcanic dykes and sills. During the 2001 field season, 10 traverses were completed and a total of 140 samples collected. The original quarter-mile airphotos of Bailes and Syme (1989) were employed for making the cross-sections, in order that maximum use could be made of their existing geological database and archived sample set. Sampling on the cross-sections included most- and least-altered volcanic examples from each outcrop, as well as samples of synvolcanic dykes and sills to demonstrate their alteration relative to that undergone by the adjacent volcanic host rock. Empirical observations indicate

- noticeable variations in the epidote to quartz content of altered, pillowed to massive flows;
- the presence of semiconformable zones of silicification and disseminated sulphide mineralization; and
- discrete, discordant zones of sulphide veining and vesicle infilling unrelated to the known massive sulphide deposits.

DETAILED SUBPROJECTS

Baker-Patton Rhyolite Complex Alteration Study (Dianne Mitchinson [M.Sc. student, LU] and George Gale [MGS])

The Baker-Patton Rhyolite Complex is the easternmost VMS-hosting domain within the Flin Flon volcanic-arc assemblage (Fig. GS-1-1) and, taking into account folding and fault duplication, is the largest volume of felsic volcanic rock within this part of the Flin Flon Belt. Due to several bounding regional faults, its relative stratigraphic position to other components in the central Flin Flon Belt remains unknown. Despite its large volume, it is host to only small past-producing mines (Pine Bay, Don Jon and Northstar) and subeconomic occurrences (Baker-Patton, Cabin zone and Leo Lake). At the request of companies working in the area, a complex-wide alteration study was undertaken to determine whether hydrothermal-mineral alteration vectors would assist in the further evaluation of the area's VMS potential.

The main thrust of this study is an X-ray diffraction (XRD) mineral and electron microprobe mineral-chemical study of archived and infill samples, the latter collected during the 2001 field program. The objective is to complete a mineral-alteration map of the entire Baker-Patton Complex. One goal of the 2001 field program was to generate field-based lithological and alteration maps that will provide a 'reference frame' in which to evaluate the XRD and mineral-chemical study. This is necessary because the XRD study will be dominated by archived samples. With this objective in mind, samples were collected that best represent 1) relatively unaltered to strongly altered rhyolite units of the complex, and 2) various physical components of the rhyolite flows (altered and unaltered massive facies, lobes and microbreccia).

With these samples, we can place XRD alteration mineralogy into its context (e.g., flow facies and degree of alteration) within individual rhyolite flows. This will provide the framework for evaluating the XRD alteration mineralogy relative to various VMS deposits and occurrences in the Baker-Patton Complex.

Flin Flon Hanging-Wall Alteration Study (Doreen Ames [GSC])

One of the most interesting and least known aspects of VMS metallogeny is the nature and extent of alteration halos within the hanging-wall stratigraphy to massive-sulphide deposits. Hanging-wall alteration can be formed as a result of the continuation of hydrothermal activity after burial of lava flows or by the generation of argillaceous hydrothermal sediments (e.g., by prolonged low-temperature exhalations in the waning stages of ore formation at depth). This concept was reinforced by studies of the Home (Kerr and Gibson, 1983), Kidd Creek (Barrie et al., 1999) and Ansil (Galley, 1994; Galley et al., 1996) VMS deposits, which demonstrated that at least some thickness of hanging-wall stratigraphy was present as the economic portions of these deposits were formed or reworked. Hydrothermal-fluid leakage has been documented 500 m upsection from the Ansil deposit (Galley et al., 2000). If the nature and extent of this hydrothermal leakage can be quantified, it may become an ideal exploration tool to focus in on potential VMS-hosting stratigraphic intervals. These processes may also lead to the development of stacked ore lenses (e.g., Amulet A and Upper A deposits, Noranda); therefore, the potential exists within hanging-wall alteration haloes for future discoveries higher in the stratigraphy.

The Flin Flon hanging-wall study is based on detailed observations of volcanic-flow facies changes and alteration characteristics within the thick succession of massive to pillowed Hidden Lake basalt and basaltic andesite flows (Bailes and Syme, 1987). These basalt flows directly overlie the rhyolite and volcanoclastic host strata to the Flin Flon, Triple 7 and Callinan deposits (Fig. GS-1-2). One of the most interesting aspects of this basalt succession is the occurrence of abundant interpillow sediment, composed of varying ratios of hydrothermal chert, hyaloclastite and alteration minerals. These hydrothermal-hyaloclastite sediments form cohesive interflow units at several levels of the hanging-wall stratigraphy, with one of the thickest units marking the top of the Hidden Lake basalt between Louis and Phantom lakes (Fig. GS-1-2). The amount of sediment present in this formation, and its high degree of hydrothermal modification, suggest that it was an ideal medium for migrating hydrothermal fluids.

Six sections were completed across the Hidden Lake basalt from the north end of Phantom Lake to the Club Lake Fault, where the section is in fault contact with younger Missi Group sedimentary strata (Fig. GS-1-2). In addition to detailed section mapping at 1:2000 scale, occurrences of interflow and interpillow sediment were sampled (more than 200 samples) to evaluate variations in mineralogy, mineral chemistry, and major- and trace-element chemistry.

Fieldwork next summer will involve the completion of several surface and drill-core sections where the hanging-wall strata are overlain by the infrastructure of the town of Flin Flon, and a more detailed examination of a possible high-temperature reaction zone associated with sills low in the hanging-wall section, between the Railway and Club Lake faults.

Triple 7 Hanging-Wall Stratigraphy and Alteration Study (Nicole Tardif [M.Sc. student, LU])

Whereas the hanging-wall study by Ames is taking a regional-scale approach to determining the presence of hydrothermal plumes above known and perhaps unknown deposits along the Flon Flon horizon, this study will focus on the immediate hanging wall to the Triple 7 deposit, in order to detect and document hydrothermal leakage. This study entails sampling and 1:1000 scale surface mapping of the hanging-wall Hidden Lake basalt above the Triple 7 VMS deposit, between the lower contact of the basalt with the Railway Volcanoclastic unit and the axial trace of the Hidden Lake F_2 synform (Fig. GS-1-2). This area (approximately 300 by 600 m) directly overlies the up-plunge extensions of the two 'arms' of the Triple 7 and the Callinan South massive-sulphide lens. To date, four principal flow units have been defined, along with numerous dykes and sills of varying compositions and ages. Some flow facies are characterized by abundant interpillow sediment and by altered pillow cores. Disseminated sulphide mineralization appears to be restricted to certain parts of the stratigraphy and is probably related to the distribution and variability of primary permeability, and the possible damming effect of basalt feeder dykes.

Mapping has also identified several low-angle, deformed faults, the presence of which supports the occurrence of an early, thin-skinned, fold-thrust event. This is important because of the potential displacement and duplication of both volcanic stratigraphy and associated massive sulphide bodies. These results will be linked with the structural study presently being carried out underground by HBMS.

Following surface mapping and sampling, two drillholes were chosen for logging and sampling. These long holes, collared several hundred metres into the Hidden Lake basalt formation, intersected the Triple 7 sulphide mineralization at depth. These drillholes permit detailed sampling for alteration directly above the economic portion of the mineralization. Approximately 200 samples collected during the 2001 field season are currently being processed for petrographic and geochemical analysis.

Stratigraphy and Structure of the Flin Flon Mine Area

The Flin Flon VMS-hosting stratigraphy includes a variable and complex suite of rocks affected by deformational events that include stratigraphy-parallel thrust faults. In 2001, a number of projects were initiated that are designed to elucidate both the detailed stratigraphy and the structural modification of the Flin Flon mine horizon. They include

- 1:500 scale mapping of the mine area;
- structural studies of the mine-hosting stratigraphy; and
- a facies analysis of volcanoclastic rocks within the stratigraphic footwall to the main ore deposits.

1:500 scale mapping (Alan Bailes [MGS], Harold Gibson [LU], Ric Syme [MGS], Ghislain Tourigny [SGS] and Debbie Bray [B.Sc. student, U of M])

Effective delineation of the VMS-hosting stratigraphy at Flin Flon has been hampered in the past by the location of the mine stratigraphy along the border between Manitoba and Saskatchewan, with the attendant division of responsibilities between two provincial geoscience agencies. Cross-border mapping at 1:500 scale was undertaken to resolve some long-standing controversies about the location and nature of the Flin Flon mine horizon. The 1:500 scale of mapping was chosen because less detailed scales were totally inadequate for effective portrayal of the geological features required to resolve structural and stratigraphic problems in the mine area. The 1:500 scale mapping program will continue into the 2002 field

season and probably beyond. In 2001, 1:500 scale mapping projects were undertaken

- around the South Main shaft by Alan Bailes and Ric Syme (MGS), including detailed mapping and study of primary features in the South Main Rhyolite Complex by Debbie Bray (B.Sc. student, U of M); and
- on 'Millrock Hill' by Harold Gibson (LU), Ghislain Tourigny (SGS), Alan Bailes (MGS) and Ric Syme (MGS).

South Main mapping

Cross-border mapping at 1:500 scale was undertaken in the vicinity of the Flin Flon South Main shaft (Preliminary Map 2001F-2) to resolve some long-standing controversies about the location of the southern extension of the Flin Flon mine horizon. The South Main area has been mapped several times at less detailed scales, with differing geological interpretations of this important area and conflicting implications for the location of the Flin Flon mine horizon.

Mapping by Stockwell (1960) at 1:12 000 scale indicated that the ore-hosting rhyolite for the Flin Flon VMS deposit linked to the south with some large rhyolite complexes (north of the South Main shaft) in a broad, curving, open Z-shaped structure, and then with smaller rhyolite complexes farther to the south at 'Millrock Hill'. Mapping at 1:20 000 scale by Bailes and Syme (1989) suggested that 1) the mine horizon continues straight to the south and east of the South Main shaft area; 2) the rhyolite complex north of the South Main shaft comprises high-level intrusions still in the footwall stratigraphy to the mine; and 3) the mine horizon is structurally offset, perhaps by a dextral fault, to link up with rhyolite complexes at 'Millrock Hill'. Mapping at 1:10 000 scale by Thomas (1992, 1994) supported this finding but proposed that offset of the mine-hosting rhyolite package was the product of folding and not a consequence of a fault. Geologists from HBED and HBMS have generally supported the interpretation proposed by Stockwell (1960) but have considered the possibility that the Flin Flon-Triple 7 and Callinan VMS mineralization represents the product of two mineralizing events (i.e., two horizons).

One objective of the B.Sc. thesis study of the South Main Rhyolite Complex by Debbie Bray is to determine whether primary features, geochemistry and map distribution of the South Main Rhyolite Complex support an intrusive or extrusive origin, and whether or not this rhyolite complex is the extension of the 'Mine rhyolite' that hosts the Flin Flon VMS deposit. The objective of the 1:500 scale mapping by Bailes and Syme is to provide the broader geological context for the South Main rhyolite bodies and a more refined stratigraphy for the Flin Flon mine area. The projects will together provide a single 1:500 scale map of the South Main area (Preliminary Map 2001-F2).

These projects have considerably refined our geological understanding of the South Main area and have brought to light a number of critical pieces of information which, although preliminary at this point, challenge some of the currently held views about the setting of the Flin Flon VMS deposit. Some of the more important observations are:

- The South Main rhyolite is composed of three recognizable units that are part of a flow-dome complex. Although parts of the rhyolite complex are clearly intrusive, there is considerable evidence that the complex is, at least in part, extrusive.
- The South Main rhyolite is emplaced/extruded within a volcanoclastic package (previously unrecognized) that is composed of mafic wacke-siltstone, monolithologic rhyolite breccia, and arenite containing detrital quartz and lithic felsic clasts. The South Main volcanoclastic package shares many characteristics with those hosting rhyolite bodies at 'Millrock Hill'.
- Basalt flows stratigraphically overlying the South Main Rhyolite Complex are broadly folded and appear to correlate with similar flows directly to the south, across the trace of the fault proposed by Bailes and Syme (1989) and the fold proposed by Thomas (1992).

These observations raise some serious questions about the Flin Flon mine stratigraphy as proposed by Bailes and Syme (1989). Clearly, further 1:500 scale mapping and systematic geochemistry of both basalt and rhyolite flows in the immediate Flin Flon area are needed to resolve this important geological issue. A key outcome of understanding the stratigraphy in the immediate area of the Flin Flon mine horizon will be more effective identification of the mine-hosting package elsewhere and more cost-effective exploration of this sequence on the east side of the Hidden Lake syncline, in Manitoba, and on the west side of the Flin Flon anticline, in Saskatchewan.

Millrock Hill mapping

The 1:500 scale mapping of Millrock Hill (Preliminary Map 2001F-1) builds upon previous 1:5000 scale mapping by Price (unpublished map, Hudson Bay Exploration and Development Co. Ltd., 1992) and a detailed report by Syme (1998). The structural geology of the area is reported in the next section.

The predeformation Millrock Hill geology comprises volcanoclastic rocks that are interpreted to have infilled a volcanic-tectonic depression on an underlying basalt sequence. The volcanoclastic rocks, which were accompanied by extrusion of rhyolite complexes, had a dual mafic and felsic source. The basalt breccia and mafic components in these volcanoclastic rocks are interpreted to have been derived from an external source (i.e., basalt basement from the margins of the depositional basin). The felsic components are interpreted to have been derived locally within the basin from the syndepositional rhyolite domes. Rapid thickness variations of some units in the depositional basin indicate that synsedimentation subsidence occurred during infilling of this volcanic-tectonic depression.

Determining the provenance and mechanism of deposition of the volcanoclastic rocks in the volcanic-tectonic depression could play an important role in guiding VMS exploration in the mine sequence at Flin Flon. A separate M.Sc. project by Christine Devine, targeting this aspect of the volcanoclastic rocks, is described in a following section.

Structural observations on Millrock Hill (Ghislain Tourigny [SGS])

Structural observations are being collected concurrent with 1:500 scale mapping. The objective is to delineate structural events that have affected the mine-hosting stratigraphy. This report summarizes structural observations made in the Millrock Hill area during the 2001 field season. The structures are shown on Preliminary Map 2001F-1 of the Millrock Hill area.

Planar and linear structural elements observed at Millrock Hill result from two principal generations of structures, D_1 and D_2 . The D_1 structures formed a weak S_1 foliation that is mainly observed in the hinge zone of F_2 folds, where it lies at a high angle to the dominant regional schistosity, S_2 . The S_1 foliation is subhorizontal and seems almost completely transposed and obliterated by S_2 . At the outcrop scale, S_1 has no significant effect on the geometry of strata.

The D_2 deformation produced the prominent folds (F_2), the associated axial-planar regional S_2 schistosity, L_2 lineations and late D_2 fault zones. The structural pattern of the area is dominated by the presence of a major F_2 fold, which is obliquely truncated and dismembered by northwest-trending ductile faults (Preliminary Map 2001F-1). This fold, a major synclinal flexure plunging at 35° toward the southeast, is largely responsible for the spatial distribution of rock types. Most outcrops are located on its west limb, where a series of parasitic, Z-shaped F_2 folds are well developed within interlayered volcanoclastic units. Metre-scale, Z-shaped F_2 folds are homoaxial and plunge moderately ($30\text{--}40^\circ$) toward the southeast. They are tight and similar in style. The regional S_2 schistosity is essentially coplanar with the axial plane of F_2 folds. The S_2 planes contain a strongly developed stretching lineation (L_2), defined by elongation of ellipsoidal markers such as lapillis and blocks in volcanoclastic flows, as well as by the elongation of amphibole crystals or aggregates of phyllosilicates. These lineations plunge at a general angle of 35° toward the southeast and are essentially collinear with the F_2 fold axis.

A well-developed network of anastomosing fault zones formed at a very low counter-clockwise angle to S_2 (Preliminary Map 2001F-1). Fault zones vary from 15 cm to 2 m in width, show a lateral continuity of several hundred metres and dip steeply to the east. The fault zones contain rock types with a steep east-dipping foliation and well-developed extension lineations. Fault rocks consist of chlorite-epidote-carbonate schist with local protomylonite. The fault-zone foliation and lineations represent accentuated S_2 and L_2 fabrics. Within the faulted rock panels, the inherited S_2 schistosity is slightly reoriented and bends to the left, thus indicating a sinistral displacement in plan view. The extension lineations plunge at an average angle of 35° toward the southeast; this attitude mimics perfectly the L_2 lineations external to the faulted panels. The attitudes of the internal foliation and the extension lineation within the fault zones indicate that these structural discontinuities are northwest-verging, oblique-reverse faults with minor sinistral displacement. They are interpreted as late D_2 structures.

A set of younger, north-northeast-trending brittle faults produced right-lateral displacement of lithological contacts and earlier structures (Preliminary Map 2001F-1). These dextral strike-slip faults are subvertical and less than 1 m wide. The dextral strike-slip displacement measured along these brittle faults reaches a maximum of 18 m in plan view.

The finite geometry and styles of major tectonic structures recognized in the Millrock Hill area result from a northeast-to-east-northeast-trending subhorizontal shortening and oblique, dip-slip elongation. The anastomosing character of the major D_2 fault system suggests a bulk inhomogeneous flattening type of deformation.

Analysis of footwall volcanoclastic rocks (Christine Devine [M.Sc. student, LU])

Volcanoclastic rocks within the footwall to the main ore deposits in the Flin Flon mine stratigraphy have previously received only limited detailed analysis (e.g., Syme, 1997, 1998). The main purpose of this study of the volcanoclastic rock package is to analyze the basin in which they occur, across the mine section from its northernmost edge, exposed near the surface expression of the Callinan deposit, to its southern edge, exposed at Millrock Hill. The three main objectives of this study are to

- determine the mechanism of emplacement of the various breccia units within the volcanoclastic package;
- ascertain their provenance; and
- identify their environment of deposition.

Four main areas in the volcanoclastic basin have been examined. In each area, a detailed stratigraphic section (or sections) has been measured to document up-section variations in depositional units with respect to clast size. In addition, clast counts and measurements were taken along these sections where variations in the units were observed. Clast counting involved measuring the three largest clasts of each rock type within a square area. A grid was used to perform a clast count in each area, thus identifying the percentage of matrix and different clast types present. A detailed description of each unit includes the sorting, matrix composition and relationship to other depositional units, along with a detailed description of contained clasts (including their colour, shape, size range, amygdule or phenocryst size and percentage, and orientation). Trace-element geochemistry and petrography of significant clast components will further identify the source and significance of the clasts in the volcanoclastic rocks. Mapping of two areas at 1:500 scale was undertaken within the mine site to augment information collected on the breccia units across the basin.

FUTURE PLANS

During the 2001 field season, emphasis was on 1) initiating field work for M.Sc. and B.Sc. thesis studies; and 2) acquiring sample sets for the alteration studies (oxygen isotope study, Bear Lake study, Flin Flon hanging-wall study). The cross-border 1:500 scale mapping and structural studies that were initiated during the 2001 field season will be the major emphasis of the 2002 field season. In 2002, the B.Sc. theses will be completed and M.Sc. thesis studies will be into data processing and initial write-up. The alteration and the VMS studies will proceed with analysis of samples collected during 2000 and 2001; where required, further samples will be collected and analyzed in 2002.

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SUMMARY

- The volcanic section in the Wabishkok Lake area is dominated by pillowed basalt, derived gneiss and intercalated gabbro, interpreted as arc-type rocks. Massive to fragmental felsic volcanic rocks and minor mafic volcanic breccia units occur within the volcanic section in the east part of the map area.
- Regional foliation in the Wabishkok Lake area is interpreted as a product of an early deformation event (F_1). Other structural features associated with the first deformation are not preserved; thus, the configuration of early fold structures and the extent of any structural repetition are not known. Northeast-plunging F_2 folds are distinguished from shallower, east-plunging lineations associated with the F_3 Wabishkok Lake antiform, which is delineated by the regional S_1 foliation pattern. This major fold structure, the hinge line of which extends through an early pluton in the centre of the map area ('Pistol Lake granodiorite'), trends east-northeast, roughly parallel to the margin of the greenstone belt. The F_3 deformation caused partial dispersion of F_2 minor fold attitudes. Late F_4 brittle deformation resulted in minor faulting and localized tectonic breccia.
- Most occurrences of surficial mineralization occur within basalt, but one of the most significant economic prospects in the Wabishkok Lake area is associated with felsic volcanic rocks. Rhyolite at Blueberry Lake, in the east part of the map area, contains several massive pyrite-pyrrhotite ($\pm$ chalcopyrite) layers up to 1.5 m thick; assay data indicate moderate Zn and Au contents. A massive to fragmental rhyolite unit between Wabishkok and Kotyk lakes, which is possibly part of the same formation, contains sporadic gossan domains derived from pyritic mineralization. Electromagnetic conductors locally intersect the margins of the latter rhyolite unit, which occurs within a gabbro sill. In basaltic rocks, rusty weathering zones with sulphide mineralization are locally associated with minor felsic porphyry intrusions and silicic alteration. The mineralization occurs both within mafic flows and at basalt-gabbro contacts. Recent exploration has focused on a gold-bearing, sulphide-oxide-facies iron formation in the gabbroic terrane between Wabishkok Lake and Lac Aimée.

INTRODUCTION

A four-week geological mapping program was conducted in June in the Wabishkok Lake area, on the north flank of the Flin Flon greenstone belt (Fig. GS-2-1). This project was designed to extend detailed (1:20 000 scale) map coverage north from the Lac Aimée-Naasap Lake area (Gilbert, 1997, 1999), in order to

- investigate the regional structure, geochemistry and tectonic affinity of the volcanic rocks in the Wabishkok Lake area;
- investigate the age and origin of major intrusive units; and
- investigate all mineral showings and assess their economic potential.

Mapping was conducted from a base on Wabishkok Lake, accessible to four-wheel drive vehicles via a rough logging road at kilometre 34 on the road to Sherridon. Comprehensive map coverage was achieved in the volcanic terrane in the vicinity of Wabishkok Lake, as far as Blueberry Lake in the east, and north to within 0.5 km of the volcanic rock-sedimentary gneiss contact south of Kisseynew Lake (Fig. GS-2-1, -2). Preliminary results indicate that the area contains arc-type volcanic components, intruded by early gabbroic and granitoid intrusions. The map area is located in the Wabishkok Lake fault block, which is the northernmost component of the Amisk collage in this part of the Flin Flon greenstone belt (Gilbert, 1999). The Amisk collage (1.92–1.87 Ga; Lucas et al., 1996) is a Paleoproterozoic accretionary complex that contains diverse volcanic rock suites; these have been compared to various modern analogues, such as intra-oceanic arc basalt and MORB-like rocks of arc-rift and/or ocean-floor origin (Stern et al., 1995a, 1995b; Syme et al., 1996; Gilbert, 1996).

Supracrustal rocks in the Wabishkok Lake area consist almost entirely of basaltic flows, intercalated with associated intrusive units (Table GS-2-1). Rhyolite is only a minor component of the volcanic sequence, and volcanic fragmental rocks are rare. No sedimentary rocks have been recognized, although iron-formation in the terrane between Wabishkok Lake and Lac Aimée may extend into the south part of the map area. Limited data in the south part of the Wabishkok Lake fault block, north of Lac Aimée, indicate the basalt in that area is tholeiitic (Gilbert, 1999). Field data from the volcanic sequence in the tholeiitic Wabishkok Lake area are consistent with an arc-volcanic affinity; geochemical data to confirm the origin of these rocks is expected to be available before the end of this year.

STRUCTURE

The first tectonic event that affected rocks in the Wabishkok Lake area was crustal-scale faulting that accompanied 1.88–1.87 Ma tectonic accretion of the Amisk collage (Lucas et al., 1996), when the Wabishkok Lake fault block was juxtaposed against strata of the Kisseynew sedimentary basin immediately to the north (Fig. GS-2-1). The contact between

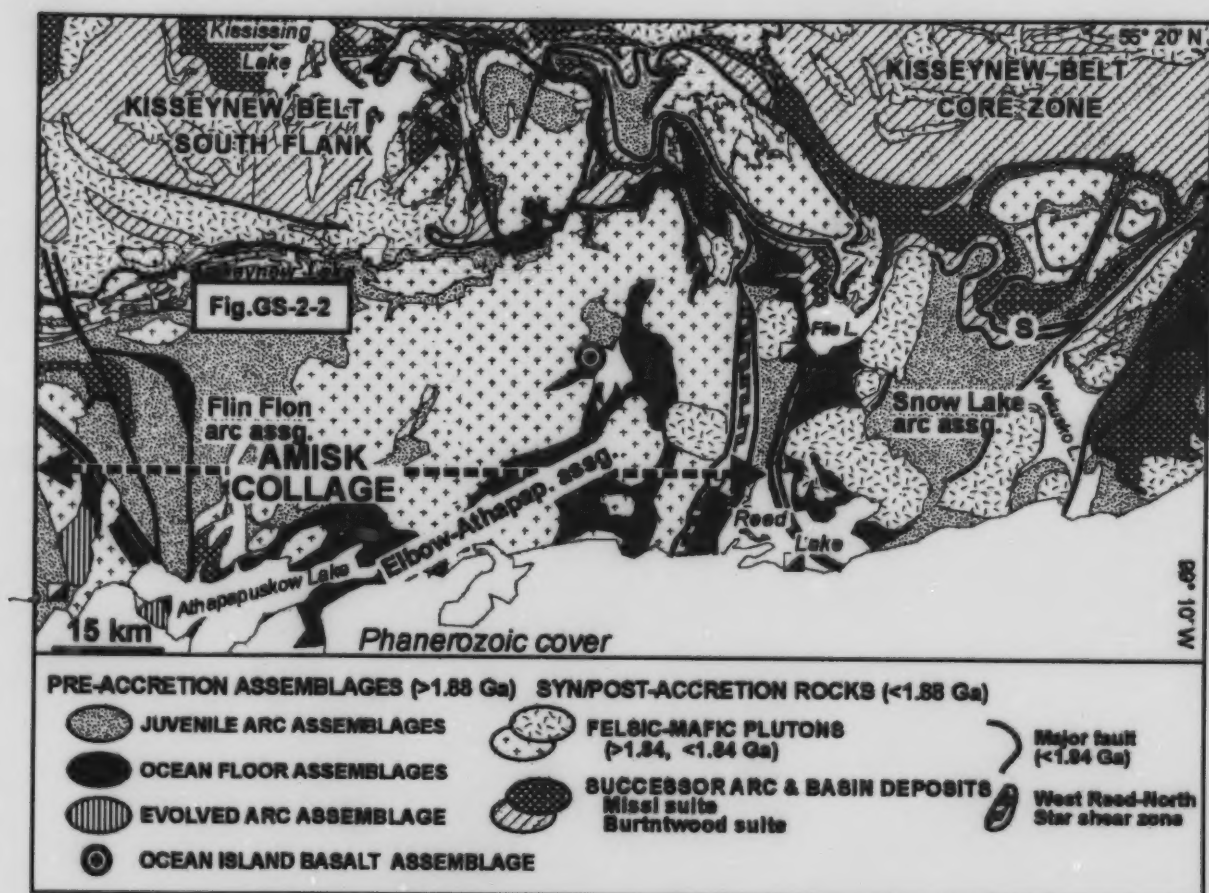


Figure GS-2-1: Simplified geology of the Flin Flon greenstone belt, showing the major tectonostratigraphic assemblages and location of the Wabishkok Lake area.

Wabishkok Lake area volcanic rocks and the metasedimentary gneiss to the north has been interpreted as faulted to locally stratigraphically conformable, suggesting that the margin of the greenstone belt locally represents a facies transition between volcanic rocks to the south and turbidite-type, epiclastic deposits in the Kiskeynew basin to the north (Zwanzig and Schledewitz, 1992). Thus, in contrast to many of the components of the Amisk collage that were tectonically transported during the accretionary event, the Wabishkok Lake fault block may not have been affected significantly by such transport, and probably occupies approximately the same site as the volcanic edifices from which it is derived.

Four deformation phases postdate tectonic accretion in the Wabishkok Lake area. The structural history is defined by features such as minor folds, lineations and faults that affect the regional foliation, which is interpreted as a product of the earliest deformation phase (F_1). The regional S_1 foliation is assumed to have been associated with major folds, but the attitudes of the hypothetical F_1 structures are unknown because planar features such as bedding or flow layering, which may have contained F_1 minor folds, are not preserved in the map area. The F_2 deformation resulted in northeast-plunging minor folds (mainly Z-asymmetrical) that range from open flexures to tight similar folds, locally associated with axial-planar, strain-slip cleavage (Fig. GS-2-3). These structures are distinguished from east-trending, shallowly plunging F_3 folds (and various concordant 'B' lineations) that are associated with the Wabishkok Lake antiform (Fig. GS-2-4). Mineral lineations and micro-crenulations (L_3) are most conspicuous in the core of this major fold, at the eastern end of Wabishkok Lake (Fig. GS-2-5). A plot of all S_1 foliations in that area, where the F_3 fold closure is defined by the trace of the regional foliation, indicates that the shallow, easterly plunge of the major fold axis approximates the average of all F_3 lineations and minor fold axes in the map area (Fig. GS-2-4, -6). The east-northeast trend of the shallowly plunging Wabishkok Lake antiform is roughly coincident with the volcanic rock-metasedimentary gneiss contact at the north margin of the greenstone belt, which apparently represented a significant influence on the attitude of the fold. The last deformation phase (F_4) consisted of localized brecciation, shearing and faulting, generally at a high angle to the regional foliation. This brittle deformation was commonly accompanied by retrogressive metamorphism, characterized by epidote-chlorite-quartz mineral assemblages (Fig. GS-2-7).

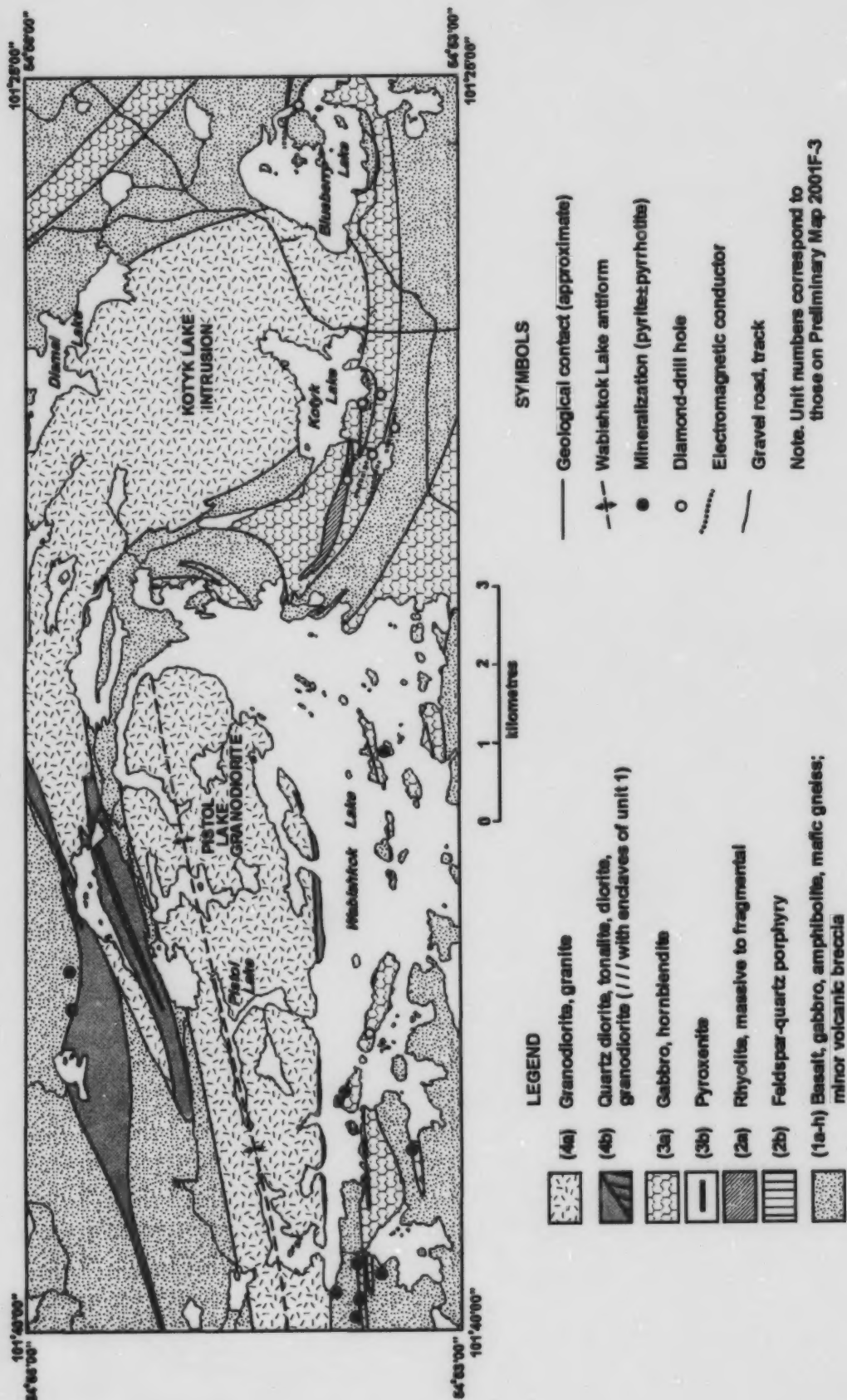


Figure GS-2-2: Generalized geology of the Webishkok Lake area.

Table GS-2-1: Geological map units in the Wabishkok Lake area.

INTRUSIVE ROCKS

Granodiorite, granite, quartz diorite, tonalite, minor diorite (4)

- (4a) Granodiorite, granite, minor pegmatite and aplite
- (4b) Quartz diorite, tonalite, minor diorite and granodiorite

Gabbro, pyroxenite (3)

- (3a) Gabbro, minor hornblende
- (3b) Pyroxenite

VOLCANIC ROCKS

Rhyolite, felsic porphyry (2)

- (2a) Rhyolite, massive to fragmental
- (2b) Feldspar-quartz porphyry

Basalt, related intrusive rocks and derived gneiss (1)

- (1a) Aphyric basalt and derived gneissic rocks; related gabbro
- (1b) Gabbro (synvolcanic)
- (1c) Aphyric and pyroxene-phyric pillowed basalt
- (1d) Monolithic volcanic breccia
- (1e) Heterolithic volcanic breccia



Figure GS-2-3: F_2 fold and associated axial-planar strain-slip cleavage at the eastern end of Wabishkok Lake.

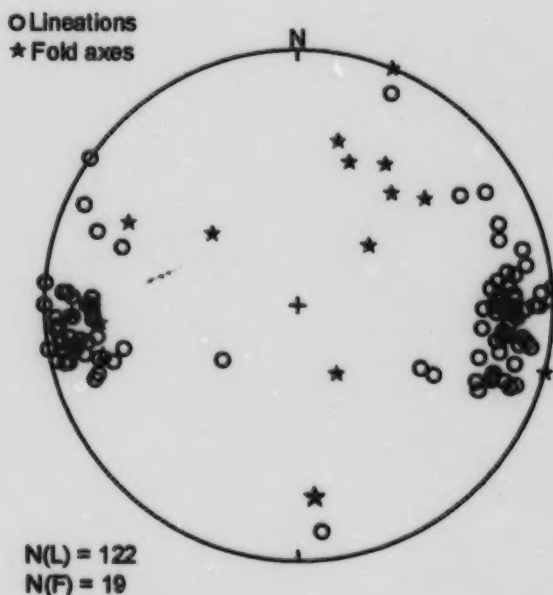


Figure GS-2-4: Lower-hemisphere stereographic plot of minor folds and lineations in the Wabishkok Lake area.

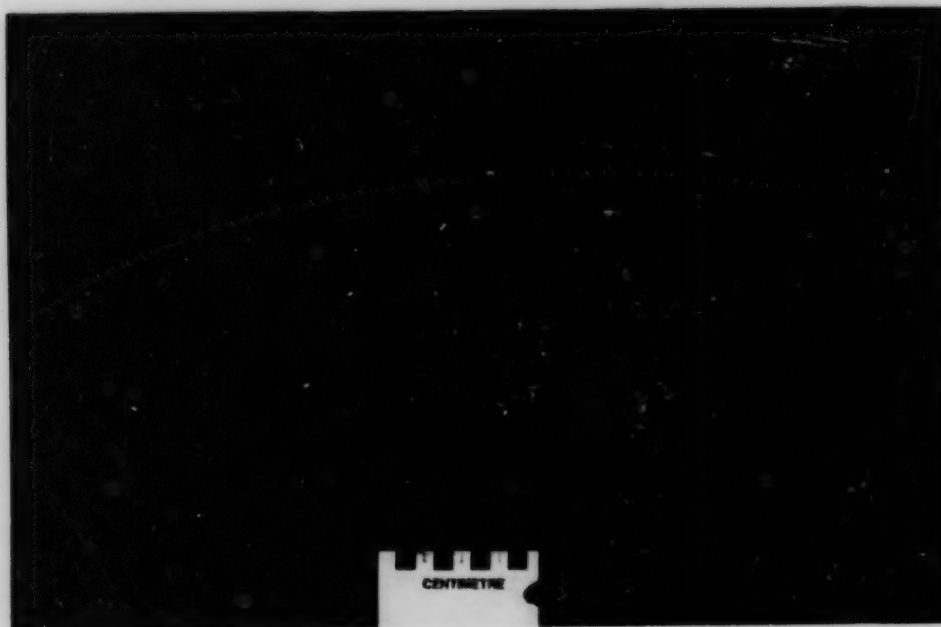


Figure GS-2-5: L_3 lineation in amphibolitic gneiss, slightly deformed by an F_4 fault at the eastern end of Wabishkok Lake.

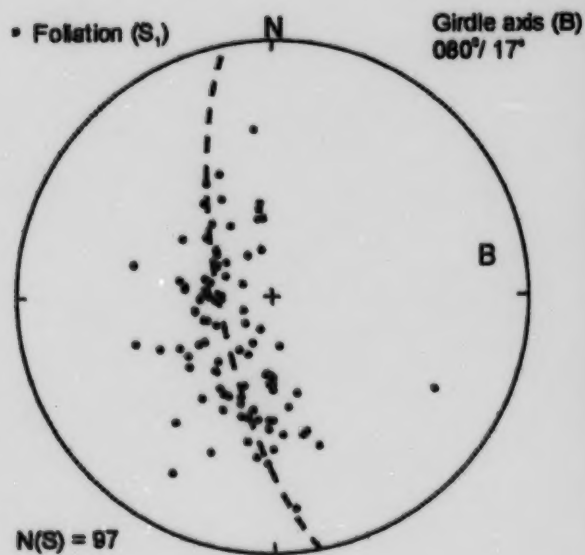


Figure GS-2-6: Lower-hemisphere stereographic plot of S_1 foliation in the eastern Wabishkok Lake area.



Figure GS-2-7: Late (F_4) tectonic breccia with massive epidote matrix in gabbro close to the western end of Wabishkok Lake.

STRATIGRAPHY

Aphyric Basalt and Derived Gneissic Rocks; Related Gabbro (1a)¹

Aphyric basalt, amphibolite, derived gneiss and schist (1a) constitute over 90% of supracrustal rocks in the Wabishkok Lake area. The mafic volcanic rocks occur in a uniform stratigraphic sequence devoid of sedimentary intercalations, although rare interflow units of autoclastic breccia (up to 0.4 m thick) are locally preserved. Pillow structure is present in only a minority of units, although pillows occur in all parts of the volcanic section. North-facing pillow tops were recognized at several places in the southwest corner of the map area, where pillowed flows are best preserved. At that locality, moderately flattened pillows are typically 0.5 to 2 m long and characterized by 1 to 5 mm long amygdules of quartz±feldspar, or rare carbonate. The flows weather medium to dark gray-green and have dark chloritic selvages that are locally cored by saussuritized plagioclase. Several occurrences of 'mattress' pillows (up to 5 m long) also occur in the section. Some pillows contain conspicuous, large quartz amygdules (up to 8 by 1.5 cm) toward their margins and large open vugs in pillow cores. Radial pipe-amygdules occur in several units.

Minor epidotic alteration occurs sporadically throughout the Wabishkok Lake basalt. In the southwest part of the map area, epidotization is locally pervasive in concordant zones up to 10 m wide. Several ages of epidotization are recognized, including early, syngenetic (sea-floor) alteration and subsequent introduction of epidote in concordant veins and younger joint sets. Tectonic breccia associated with late, brittle deformation (F_4) is characterized by a massive epidote matrix (Fig. GS-2-7). Conformable pyritized zones (0.2 to 0.5 m wide) occur locally, within or at the margins of basaltic flows. The mineralized zones, which contain up to 5% disseminated to stringer pyrite (±pyrrhotite and traces of base metals), are commonly associated with silicic alteration and are locally strongly sheared. Silicification and mineralization are locally spatially related to concordant units of felsic porphyry (2b) within the basaltic section. Amphibolitic gneiss and schist occur in strongly attenuated zones toward the margins of the volcanic terrane, and also in localized areas adjacent to altered, epidotized basalt domains or mineralized zones. The mafic gneiss commonly displays a thinly laminated, dynamometamorphic fabric, with concordant epidotic layers (2–10 mm) derived from altered domains and selvages in pillowed flows, and subordinate quartzofeldspathic stringers. Elsewhere, the lamination is very fine (0.5–2 mm) and defined by grey- to green-weathered tones that reflect subtle differences in mafic mineral content. The metamorphic rocks are locally porphyroblastic, with subhedral hornblende or elongate anthophyllite prisms that indicate at least a lower amphibolite grade of metamorphism. Disseminated garnets and richly garnetiferous zones (up to 30 cm wide) within amphibolitic gneiss were also noted at a few localities.

Gabbro, Synvolcanic (1b)

Synvolcanic mafic sills (1–40 m wide), intercalated with the Wabishkok Lake basalt, are generally massive to moderately foliated and locally display chilled margins. The intrusive rocks consist of mesocratic to melanocratic gabbro that contains up to 80% amphibole. At one locality, a 3 m wide gabbroic feeder dyke that truncates a volcanic flow terminates in pillowed basalt, with which it is lithologically gradational. Synvolcanic gabbro sills are texturally gradational with the massive, central parts of some flows, and the origin of some units (i.e., intrusive versus extrusive) cannot be ascertained.

Aphyric and Pyroxene-Phyric Pillowed Basalt (1c)

West-southwest-facing mafic volcanic flows of subunit 1c at Blueberry Lake are lithologically and stratigraphically distinct from basalt elsewhere in the Wabishkok Lake area. Only two localities are known for this unit, which is at least 40 m thick and consists of two distinct flows, both characterized by small, relatively undeformed amygdaloidal pillows (generally <1 m across) with thick (3 cm) selvages. Pillow cores are epidotized and display a densely packed, plagioclase-amygdaloidal texture. At the southeastern locality, hornblende pseudomorphs after pyroxene constitute up to 25% of the rock, whereas the flow at the northwestern locality is aphyric; the two flows are approximately on strike. The pillowed basalt is assumed to be stratigraphically conformable with adjacent volcanic breccia (1d), but the contact between these map units is not exposed.

Monolithic Volcanic Breccia (1d)

Basaltic breccia of probable autoclastic origin (1d) occurs on an islet in the centre of Blueberry Lake. The breccia unit is at least 2 m thick and contains exclusively mafic clasts that range widely in amygdaloidal texture; quartz amygdules constitute 10 to 50% of clasts by volume (Fig. GS-2-8). The fragments are angular to irregular in shape, locally with cusped margins. Remnants of chloritic rims on some clasts are similar to small, dark green tabular fragments in the monolithic breccia, which may be derived from the spalled surface of a cooling flow. Basaltic flow-breccia of similar origin occurs locally within the mafic volcanic section in the southwest part of the map area, but those interflow breccia units are invariably deformed and epidotized, and original features are poorly preserved.

¹ Numbers in parentheses throughout this report refer to map units in Table GS-2-1 and on Preliminary Map 2001F-3.

Figure GS-2-8: Monolithic basalt flow-breccia with amygdaloidal fragments (1d) at Blueberry Lake.



Heterolithic Volcanic Breccia (1e)

An isolated outcrop of heterolithic volcanic breccia occurs in the central part of Blueberry Lake, adjacent to the inferred mafic flow-breccia unit (1d). The heterolithic breccia, which is provisionally interpreted as part of a debris flow, consists of unsorted, 1 to 2 m thick, coarse fragmental layers intercalated with minor lapilli-tuff beds over an outcrop width of 8 m. The breccia is mostly undeformed and contains cobbles and small blocks of basalt and subordinate felsic clasts. Mafic fragments display widely variable aphyric to plagioclase-phyric and amygdaloidal textures. The fragments are angular to highly irregular in shape, and occur in a tuffaceous matrix (Fig. GS-2-9).

Rhyolite, Massive to Fragmental (2a)

A lensoid unit of porphyritic rhyolite, up to 160 m thick and approximately 1.6 km along strike, occurs within the gabbro sill west of Kotyk Lake. The rhyolite appears to be largely massive, but contains subordinate primary fragmental zones that suggest the unit is an extrusive lava flow. Localized chilled margins at the gabbro-rhyolite contact support the interpretation that the felsic unit is a skialithic enclave within the mafic intrusion.

White- to pale grey-weathering rhyolite contains small (approx. 1 mm) phenocrysts of plagioclase (up to 15% of the rock) and subordinate quartz (up to 5%). The strongly foliated felsic unit is characterized by diffuse, pale grey streaks and localized iron-stained domains up to 0.6 m wide. Possible spherulitic texture was observed at one locality. A fragmental zone, over 10 m wide and close to the south margin of the rhyolite, contains grey-weathering, angular to irregularly shaped clasts up to 8 cm across. The fragments typically constitute 25 to 40% of the rock and are inferred to be autoclastic in origin. Breccia with more densely packed fragments (up to 70% of the rock) is interpreted as a transitional rock type between massive rhyolite and the marginal breccia facies (Fig. GS-2-10).

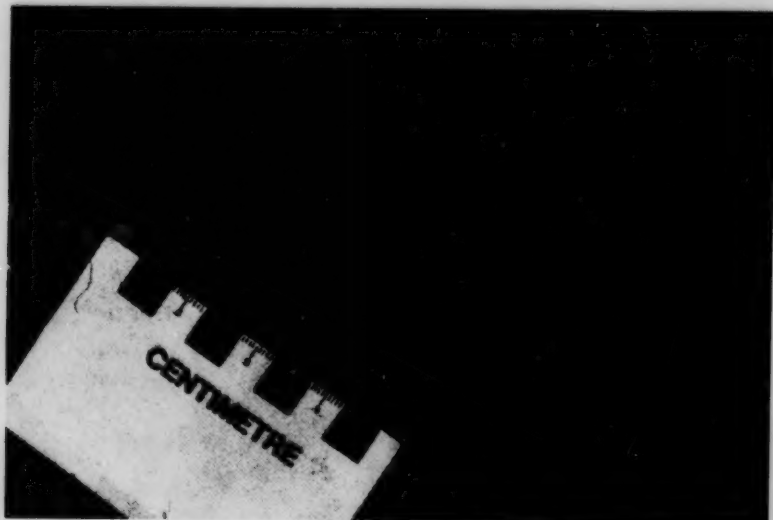
Feldspar-Quartz Porphyry (2b)

Homogeneous felsic porphyry with sparse plagioclase ($\pm$ quartz) phenocrysts occurs in several concordant units, up to 65 m thick, within the basaltic section in the southwest corner of the map area. The moderately to strongly foliated porphyry is very fine grained to aphanitic, and generally highly silicic; weathered surfaces are white, with localized,



Figure GS-2-9: Heterolithic volcanic breccia of inferred debris-flow origin (1e) at Blueberry Lake.

Figure GS-2-10: Fragmental rhyolite (2a) with densely packed, subangular to irregularly shaped clasts, west of Kotyk Lake.



diffuse, pale grey to beige streaks. The rocks locally contain minor garnet porphyroblasts (up to 5%), and display sporadic iron-stained domains. Contacts between the porphyry intrusions and volcanic rocks are typically sharp and planar; however, at one locality, contiguous amphibolite (1a) contains thin felsic veins derived from the porphyry.

The origin of subunit 2b is uncertain; the porphyry is most likely either associated with the (predominantly basaltic) volcanic sequence or related to later granitoid plutonism. Subunit 2b is provisionally interpreted as volcanic related, because the felsic porphyry is lithologically similar to massive phases in rhyolite (2a), which has been established as an extrusive unit, probably similar in age to mafic volcanic rocks (1); furthermore, the porphyry intrusions are not spatially related to any major granitoid intrusion.

Gabbro, Minor Hornblende (3a)

Large gabbro intrusions (3a) are widely distributed and equal in abundance to mafic volcanic rocks in the Wabishkok Lake area. These units are not intimately intercalated with mafic flows, in contrast to the synvolcanic mafic sills (1b). However, the two gabbroic types are lithologically similar, with hypidiomorphic, interlocking green hornblende and plagioclase crystals, or local 'spotted' texture due to equant, subhedral to ovoid amphibole. Both gabbroic units are generally massive, except for minor foliated to sheared zones close to the margins of the intrusions.

The major gabbroic sill (3a) that extends through a chain of islands in the central part of Wabishkok Lake is 0.25 to 1 km in width and is continuous with the North Aimée Gabbro southeast of Wabishkok Lake (Gilbert, 1999). The latter intrusion is interpreted as postvolcanic because it apparently truncates an inferred major fault between the Wabishkok Lake and Animus Lake blocks; limited geochemical data indicate that the intrusion is derived from a MORB-type magmatic source. The gabbro sill that extends northwest from Kotyk Lake to the east end of Wabishkok Lake is lithologically similar to the intrusion in the central part of the lake, but is locally more mafic (melanocratic to hornblenditic, with 65–95% amphibole).

Pyroxenite (3b)

A massive pyroxenite lens, approximately 20 m thick and over 70 m along strike, is emplaced within basalt (1a) in the north part of the map area. This ultramafic lens is located very close to the mafic volcanic–quartz diorite contact north of Wabishkok Lake (Fig. GS-2-2). Massive, coarse- to very coarse grained pyroxenite contains subhedral pyroxene crystals up to 1 cm long, variously altered to amphibole. Minor, finer grained zones occur at the south margin of the lens; brown mica (?phlogopite) constitutes up to 5% of the rock. The moderate to bright apple-green weathering colour of the pyroxenite contrasts with the darker grey-green tones of contiguous basalt; contacts with the basalt are not exposed. The pyroxenite intrusion, which is apparently unique in the map area, is provisionally interpreted as a tectonically emplaced, primitive fraction of the magma from which gabbro of subunit 3a is derived.

Granodiorite, Granite, Minor Pegmatite and Aplite (4a)

Two granodioritic to granitic plutons (4a) together occupy at least one-third of the map area. The Pistol Lake granodiorite is an early, pear-shaped stock located in the core of the F₃ Wabishkok Lake antiform, in the west-central part of the map area (Fig. GS-2-2). The pervasive S₁ foliation within the pluton is deformed by the major fold, the hinge line of which extends east-northeast through the intrusion. A second granitoid pluton with similar texture and composition ('Kotyk Lake intrusion'), which extends northwest from Kotyk Lake and wraps around the antiformal fold closure in the area northeast of Wabishkok

Lake, is interpreted as coeval with the Pistol Lake granodiorite.

The Pistol Lake intrusion consists of moderately to strongly foliated, biotite-bearing granodiorite and granite. The granitoid rocks contain incipient quartz eyes (2–8 mm) that are commonly lineated parallel to the shallowly plunging axis of the Wabishkok Lake antiform. Potassium metasomatism has resulted in irregular to ovoid K-feldspar aggregates (3–10 mm) and localized concordant K-feldspar-rich zones (2–25 cm wide). The white- to pink-weathering granodiorite is locally intruded by red aplite and pegmatite dykes, assumed to be a late magmatic phase of the granodiorite. Quartz-eye granodiorite to quartz monzonite southwest of Dismal Lake (Kotyk Lake intrusion; Fig. GS-2-2) contains ovoid to lenticular quartz aggregates (0.5–1.2 cm) and subhedral K-feldspar crystals (0.5–1.5 cm) that each constitute up to 40% of the rock. Biotite and subordinate hornblende constitute 5 to 8% of the rock, which is moderately foliated. Based on previous mapping (Bateman and Harrison, 1945), this intrusion is apparently continuous with quartz dioritic to granodioritic rocks (4b) in the area immediately north of Wabishkok Lake.

Quartz Diorite, Tonalite, Minor Diorite and Granodiorite (4b)

White-weathering quartz dioritic to tonalitic rocks (4b) occur in the west part of the Kotyk Lake intrusion, in the area north of Wabishkok Lake. At that locality, the south part of the map unit consists of quartz dioritic and tonalitic rocks that contain minor enclaves of partially assimilated mafic volcanic strata and associated gneisses (Preliminary Map 2001F-3); in contrast, the north part of the unit consists of homogeneous granodiorite (4a). The quartz diorite is texturally similar to the granodiorite, except for the absence of K-feldspar. Quartz diorite (4b) also occurs at the south margin of the Pistol Lake granodiorite (4a), where the contact between the two granitoid units is approximately coincident with the north shore of central Wabishkok Lake. Up to 80 m of hornblende quartz diorite to diorite (4b) are exposed at the lakeshore in the area southeast of Pistol Lake. The medium- to coarse-grained rocks are strongly foliated, with hypidiomorphic plagioclase and prominent euhedral hornblende that is locally porphyroblastic. Massive, pink aplitic veins and thin dykes (<0.5 m thick) are characteristic of the unit, and constitute up to 40% of some outcrops. Remnants of fine-grained amphibolitic gneiss derived from basalt (1a) occur at several shoreline outcrops along the contact between units 4a and 4b. A 3 m wide cataclastic zone that contains a highly sheared quartz intrusion at the south margin of the Pistol Lake granodiorite suggests that the contact between the two granitoid units is locally faulted.

ECONOMIC GEOLOGY

Most mineral showings in the Wabishkok Lake area are located within mafic volcanic rocks. The mineralization consists of localized accumulations of pyrite ($\pm$ minor pyrrhotite) and occurs both within basaltic units and at contacts between flows and synvolcanic gabbroic sills. The mineralized zones are typically partly silicified and, in some cases, contain minor felsitic intrusions. Most mineral showings are located in the southwest corner of the map area, where various stratigraphic settings are distinguished (Fig. GS-2-2; Table GS-2-2). Diamond drilling at a basalt/gabbro contact was carried out in 1951 by Hudson Bay Exploration and Development Co. Ltd., to test a conductor at the south margin of the major gabbro sill south of Kotyk Lake (Fig. GS-2-2). The drill intersected several massive-sulphide layers in basalt adjacent to the mafic sill. The layers are up to 0.75 m thick and consist largely of pyrite and pyrrhotite, with minor chalcopyrite.

Table GS-2-2: Setting of mineralization at three localities in the southwest part of the Wabishkok Lake area.

Location	Host rock	Mineralization
Within a few metres of the amphibolite-granodiorite contact at the north margin of the mafic volcanic terrane, at the western end of Wabishkok Lake	Highly sheared, silicified gneiss (0.5 m thick) within gneissic amphibolite	Pyrite, disseminated and in fine stringers, constitutes approximately 5% of the rock
Approximately 0.6 km south of the north margin of the mafic volcanic terrane.	Silicified basalt in a mafic volcanic section, adjacent to a feldspar porphyry dyke; the basalt contains subordinate gabbro interlayers and is extensively epidotized and silicified over an 80 m wide zone	Disseminated pyrite
At the margin of mafic volcanic enclaves, within the major gabbro sill that extends through the centre of Wabishkok Lake; two mineralized localities and a diamond-drill hole site occur approximately on strike over a distance of 3.5 km, along a horizon through the central part of the gabbro sill	Partly silicified basalt, associated with minor felsitic intrusive units	Pyrite $\pm$ arsenopyrite (disseminated and in fine stringers) constitutes up to 5% of the host rock. The mineralization occurs in 1–3 m wide, rusty-weathering zones

One of the most significant economic prospects in the Wabishkok Lake area occurs within felsic volcanic rocks at Blueberry Lake, close to the east margin of the map area (Fig. GS-2-2). Diamond drilling of an electromagnetic (EM) anomaly at that locality intersected massive sulphide layers up to 1.5 m thick, which contain 0.16% Cu, 0.98% Zn and 34 g/t Au (Assessment File 90485, Manitoba Industry, Trade and Mines, Winnipeg). The area was subsequently investigated by geological mapping and a humus geochemical survey (Assessment File 93337, Manitoba Industry, Trade and Mines, Winnipeg). Sulphide mineralization is hosted by highly deformed felsic volcanic rock units up to 50 m thick, associated with gabbroic sills within the mainly basaltic volcanic sequence east of Blueberry Lake (Preliminary Map 2001F-3). Five kilometres west of the Blueberry Lake mineral locality, a 160 m thick unit of rhyolite (2a) occurs within a gabbro intrusion southwest of Kotyk Lake (Fig. GS-2-2). The lensoid rhyolite unit contains localized iron-stained domains due to minor accumulations of pyrite. Two EM conductors are, in part, coincident with felsic volcanic-gabbro contacts at the north and south margins of the rhyolite unit (Preliminary Map 2001F-3).

The most recent exploration in the Wabishkok Lake area focused on the potential for gold mineralization in a sulphide-oxide-facies iron-formation that extends along strike for up to 7 km in the area between Lac Aimée and Wabishkok Lake (Gilbert, 1997; Assessment Files 93347, 94471 and 94472, Manitoba Industry, Trade and Mines, Winnipeg). Moderate amounts of Au (up to 4.1 g/t [0.12 oz/ton]) and minor Cu, Ni and Zn occur in pyrite-bearing chert laminae, and within veins of quartz and feldspar porphyry that are associated with the magnetiferous sedimentary formation (Gilbert, 1986, 1997).

ACKNOWLEDGMENTS

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**GS-3 JOSLAND LAKE SILLS: U-PB AGE AND TECTONOSTRATIGRAPHIC IMPLICATIONS
(PARTS OF NTS 63K AND 63N)**

by H.V. Zwanzig, A.H. Bailes and Ch.O. Böhm¹

Zwanzig, H.V., Bailes, A.H. and Böhm, Ch.O. 2001: Josland Lake sills: U-Pb age and tectonostratigraphic implications (parts of NTS 63K and 63N); in Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 28-32.



SUMMARY

The age, geochemistry and field relationships of the mafic, layered Josland Lake sills require a re-evaluation of the tectonic history of the Flin Flon Belt and adjacent parts of the Kisseynew Domain. A sample of quartz diorite from the upper, Fe-rich portion of a differentiated mafic sill northwest of Reed Lake has yielded a U-Pb zircon age of 1886 ± 3 Ma (95% confidence level, MSWD = 0.68) that is interpreted to be the age of crystallization of the sill. The sill, 24 km long and up to 2 km thick, belongs to the suite of Josland Lake sills. These sills have a unique geochemical fingerprint throughout their 100 km regional extent from Snow Lake and Reed Lake, in the Flin Flon Belt, to Kississing Lake, on the south flank of the Kisseynew Domain. They are interpreted to represent a major igneous province, which includes the $1881 \pm 3/2$ Ma Mikanagan Lake sills in the Flin Flon area that formed at the close of early juvenile-arc volcanism, before the pre-1876 Ma tectonic amalgamation into the Amisk collage. The trace-element geochemistry of the sills and their common occurrence in early volcaniclastic basin fill suggest that they are a product of arc rifting. Elevated platinum-group elements (PGEs) and gold deposits in the sills make them a mineral-exploration target. Because the sills intrude the Amisk collage, the Reed Lake ocean-floor assemblage and the Snow Lake arc assemblage, these various host rocks may have been part of a composite arc and back-arc terrane that separated into segments during the 1881 to 1886 Ma rifting. Structural slices of ca. 1.85 Ga metaturbidite, extending from Reed Lake into the Kisseynew Domain along volcanic arc- and back-arc-assemblage boundaries, suggest that the composite terrane was reassembled during the continental collision tectonics that involved closing of the Kisseynew basin and deformation of the 1.85 Ga turbidite.

INTRODUCTION

Large, mafic, layered sills that intrude early arc and back-arc assemblages are concentrated in several areas in the Flin Flon Belt and along the south flank of the Kisseynew Domain (Fig. GS-3-1). They include the Mikanagan Lake sills, north-east of Flin Flon (Bailes and Syme, 1989), and the Josland Lake sills (Bailes, 1980), extending from Reed Lake north and northwest to Kississing Lake (Zwanzig, 1994). The distinctive high iron contents in the upper portions of both sets of sills (some with more than 20%, expressed as Fe_2O_3) and the high albite content and Fe/Mg ratios of their most felsic differentiates suggest that these extensive sills are correlative (Zwanzig, 1994).

Validation of the correlation of the Josland Lake and Mikanagan Lake sills requires them to have a similar age of crystallization. Only one sill (Mikanagan Lake sill) has previously yielded a precision U-Pb zircon age of $1881 \pm 3/2$ Ma (Stern et al., 1999). An attempt to date zircon in the Josland Lake sills has yielded only a poorly constrained minimum age of ca. 1855 Ma (K. Ansdell, pers. comm., 2001; Connors, 1996). In this contribution, we report a new precision U-Pb zircon age from the largest Josland Lake sill northwest of Reed Lake, and discuss its regional stratigraphic and tectonic implications. Above-background values of PGEs (Peck et al., 2000) and the presence of two subeconomic gold deposits in the sills (Zwanzig, 1994) make these sills a potentially important mineral-exploration target.

GEOLOGY OF SILLS AND HOST ROCKS

The Josland Lake sills extend along a series of structural breaks from Reed Lake to Kississing Lake. They straddle the tectonic boundary between early juvenile volcanic assemblages of the Amisk collage and the coeval volcanic rocks to the east and north that, unlike the Amisk collage, are structurally interleaved with younger greywacke turbidite (Burntwood Group). The sills intrude three different volcanic assemblages: the Fourmile Island arc assemblage (part of the Amisk collage), the Northeast Reed ocean-floor assemblage and the Snow Lake arc assemblage (Fig. GS-3-1; Syme et al., 1995; Syme and Bailes, 1996). Fault slices of the Burntwood Group occupy the contacts between these volcanic assemblages. Although abundant near the fault contacts, Josland Lake sills do not intrude the Burntwood Group. The sills and their host assemblages are best preserved between Reed Lake and File Lake, an area where metamorphic grade ranges from middle greenschist facies to middle amphibolite facies and where the rocks are cut into northeast- to northwest-trending fault blocks and deformed into large upright folds (Bailes, 1980). Highly metamorphosed equivalents of the sills extend northwest to Kisseynew and Kississing lakes for a strike length of 100 km (Zwanzig, 1994, 1996). The higher grade sills are strongly foliated and attenuated, and were refolded by recumbent to upright structures during multistage continental collision (Zwanzig, 1999).

Field relationships north of Reed Lake indicate that the Josland Lake sills are early orogenic intrusions. The various sills show complex pre- and postkinematic relations to the earliest deformation of their volcanic host rocks (Bailes, 1980). Some sills postdate at least part of the early deformation in the area, and one of these was sampled for the U-Pb geochronology.

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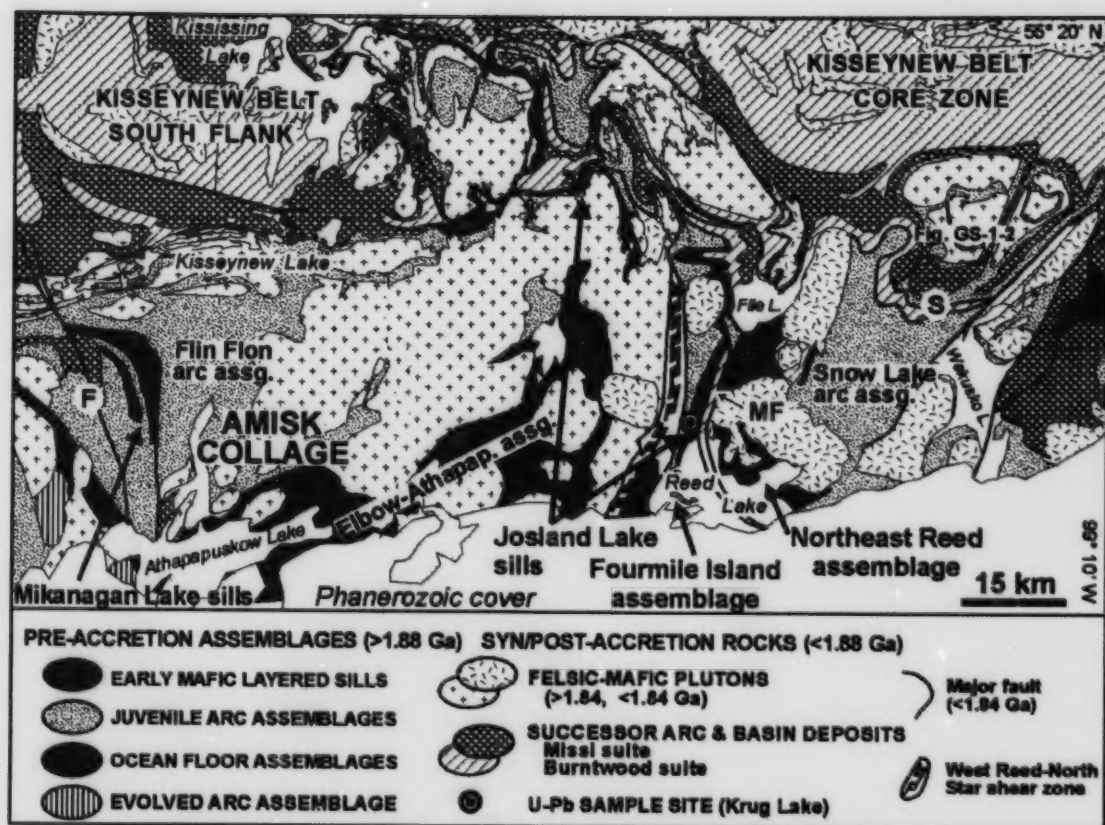


Figure GS-3-1: Simplified geology of the Flin Flon Belt and the south flank of the Kisseynew Domain, showing the tectonic assemblages mentioned in the text and the locations of major Josland Lake sills, the Mikanagan Lake sills and the sampling site for the U-Pb age.

Despite the range in metamorphic grade and structural style of the various Josland Lake sills, their composition, layering and intrusive habit are similar and closely resemble that of the Mikanagan Lake sills (Bailes and Syme, 1989). The best preserved Josland Lake sills are layered differentiated bodies that average 500 to 700 m in thickness (Bailes, 1980). They have a lower zone of leucogabbro and melagabbro, a central zone of ferrogabbro and an upper zone of granophyric quartz diorite to albite tonalite, typically in proportions of 5:3:2. The upper amphibolite-facies equivalents of the sills in the Kisseynew Domain have the same zoning as in the Flin Flon Belt but range from 150 m to only a few metres in thickness.

Gabbro zones in the sills have sharp lower contacts and chilled margins. Weak rhythmic modal layering (particularly near the top of the gabbro zones) and cumulate textures are present (Bailes, 1980). Original minerals (generally present as pseudomorphs) were augite, labradorite and ilmenite. Gabbro norite was noted in the more completely studied Mikanagan Lake sills (Bailes and Syme, 1989) and is probably also abundant but not recognized in the Josland Lake sills. In the Kisseynew Domain, gabbro is recrystallized to medium-grained amphibolite with platy and fibrous amphibole, diopside and lesser plagioclase. Sills in high-grade metamorphic areas rarely show rhythmic layering, but their lowermost division is melagabbro, containing only minor amounts of plagioclase.

Ferrogabbro zones weather black at all metamorphic grades where primary pyroxene is replaced by secondary amphibole. The base of the ferrogabbro zone, which is gradational over a few metres with the gabbro zone, shows strong rhythmic layering in the low-grade metamorphic areas, but ferrogabbro is generally uniform in the Kisseynew Domain, with scattered garnet porphyroblasts 1 to 2 mm in diameter. The upper part of the ferrogabbro in the high-grade metamorphic domain has centimetre-scale modal layering of garnet (<30%) and magnetite, and has been mistaken locally for iron-formation (Zwanzig and Schledewitz, 1992).

Granophyre zones in the Josland Lake sills grade over a short distance from ferrogabbro to quartz diorite (<40% mafic minerals) and upward to tonalite that is rich in albite (<5% mafic minerals). Some upper contacts show signs of roof-zone contamination, but thinner sills have chilled upper margins. Granophyric intergrowth between sodic plagioclase and quartz is preserved only in the lower grade rocks. Radiating clusters of metamorphic fibrous amphibole in the medium-grade rocks (Bailes, 1980) occur as a mottled gneissic texture in the Kisseynew Domain. Pale pink-weathering albite is abundant in this felsic gneiss.

GEOCHEMISTRY

The various Josland Lake sills have a single, distinctive set of geochemical characteristics similar to the Mikanagan Lake sills (Bailes and Syme, 1989). All sills show extreme iron enrichment in the ferrogabbro, quartz diorite and ferrotonalite zones (Bailes, 1980; Zwanzig and Bailes, work in progress, 2001). The major- and minor-element geochemistry of the Josland Lake and Mikanagan Lake sills is unique within the Flin Flon Belt and Kisseynew Domain, and strongly suggests that all these sills are related and were emplaced in a single tectonic environment.

Chilled gabbro falls into the field of enriched mid-ocean ridge basalt (E-MORB) on Th/Nb/Zr and Th/Yb vs. Nb/Yb diagrams (unpublished data, not shown). Extended element plots (N-MORB normalized) of chilled gabbro from various sills do not display the negative high-field-strength element (HFSE) anomalies that would be typical for arc volcanic rocks (Fig. GS-3-2a). The plots have a relatively smooth negative slope, with somewhat elevated light rare-earth elements (LREE) and Nb, similar to E-MORB. This characteristic and the slightly elevated Th are also typical of contaminated MORB and arc-rift basalt from the Flin Flon area (Fig. GS-3-2a), and are consistent with the local melting in the roof zone noted by Bailes (1980).

A systematic increase of incompatible elements in the upper zones of one typical sill is apparent in extended element plots (Fig. GS-3-2b). However, TiO_2 was contained in at least one crystallizing mineral phase; it is concentrated in the ferrogabbro and depleted in the overlying Na-tonalite, probably through crystal settling of ilmenite.

SAMPLING AND GEOCHRONOLOGY

The geochronology sample is from the 'type' Josland Lake sill, which extends from the northwest shore of Reed Lake for 24 km to the north-northeast (Fig. GS-3-1). Samples from the upper, more fractionated leucotonalite did not provide zircon for dating the Josland Lake sill (T. Gordon, pers. comm., 1989) or yielded only a 1881 ± 4 Ma titanite age for the Mikanagan Lake sill (Stern et al., 1999). The sample in this study was taken across a strike interval of 20 m lower in the sill, near the base of the quartz diorite to ferrotonalite zone east of Krug Lake (6060625N, 400234E, UTM zone 14, NAD 27). The quartz diorite at this locality consists of 2 to 4% remnant blocky clinopyroxene (overprinted by 15% ferroactinolite); 20% elongate, 3 to 15 mm amphibole phenocrysts (replaced by actinolite); 50% blocky, 1 to 3 mm, twinned sodic plagioclase (partly altered to sericite and carbonate); 10% equant, 0.5 to 1 mm quartz grains; 5% micrographic intergrowth of quartz and plagioclase; and 1 to 3% magnetite (partly altered to leucoxene).

Approximately 30 kg of Josland Lake quartz diorite (sample 07-2000-1727-1-2) were processed for U-Pb dating at the University of Alberta Radiogenic Isotope Facility in Edmonton. After crushing and Bico disc milling, heavy minerals were separated by standard procedures using a Wilfley table, methylene iodide heavy liquid and a Frantz magnetic separator. The applied U-Pb analytical methods are described in Böhm et al. (1999).

The quartz diorite sample yielded less than a dozen zircon grains in the nonmagnetic mineral separate (1.8 A), including few larger, partly resorbed crystals that contain abundant inclusions and may indicate an inherited component. After careful inspection of more magnetic fractions, however, abundant zircon (>50 grains) was recovered from the 1.0 and 0.8 A mineral separates. This more magnetic zircon generally consists of colourless to light brown prisms and fragments of poor quality. In order to minimize multiple age components, portions containing fractures, inclusions and alteration were broken off individual zircon crystals and removed. Relatively homogeneous and clean zircon fragments were subsequently air abraded. Three analyses of such single-zircon fragments yielded moderate uranium contents (613–1266 ppm) and high Th/U ratios (1.8–2.8), which is typical of zircon crystallizing from a mafic magma. The three U-Pb zircon analyses have similar $^{207}\text{Pb}/^{206}\text{Pb}$ ages, ranging from 1872 to 1883 Ma; a best-fit regression line defines an upper intercept age of 1886 ± 3 Ma (95% confidence level, MSWD = 0.68; Fig. GS-3-3).

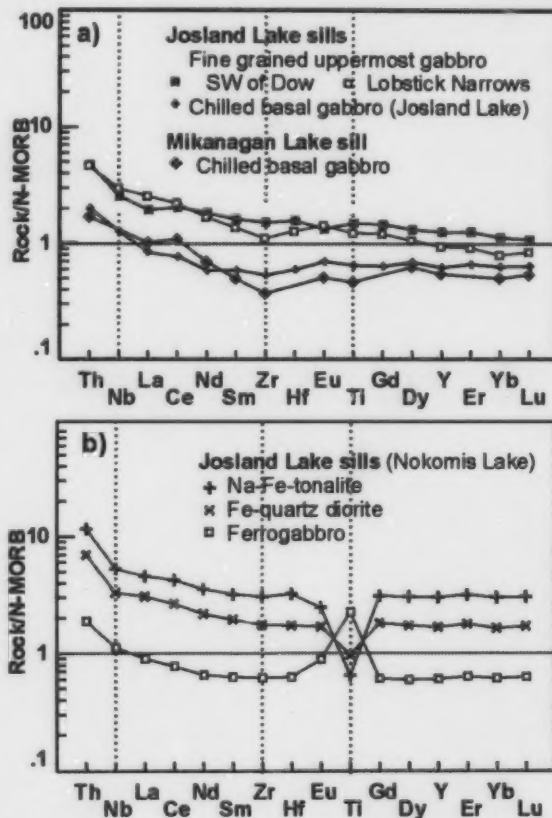


Figure GS-3-2: Extended element plots (N-MORB normalized) of a) chilled gabbro samples of the Josland Lake sills and Mikanagan Lake sill; and b) successive zones of the Josland Lake sill on Nokomis Lake, south flank of the Kisseynew Domain.

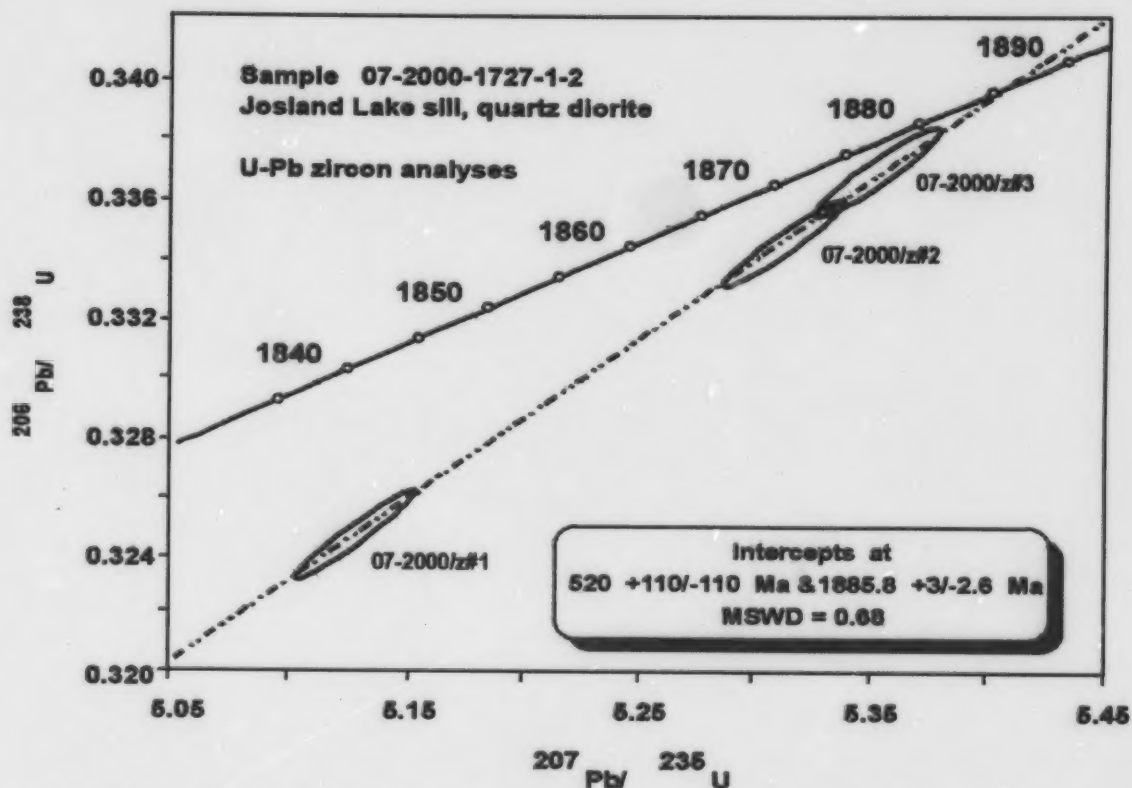


Figure GS-3-3: Concordia diagram of U-Pb zircon isotopic analyses from quartz diorite zone of layered gabbro sill (Josland Lake sill). Analytical uncertainty is 2 σ standard error.

IMPLICATIONS

The new U-Pb zircon age from Fe-rich quartz diorite in the type Josland Lake sill northwest of Reed Lake is interpreted to represent the age of crystallization of the sill. This sill belongs to the group that cuts other previously folded Josland Lake-like sills (Bailes, 1980) and therefore provides a minimum age for the latter. The close petrographic and geochemical similarity of the entire suite of Josland Lake sills and the similar age of the Mikanagan Lake sills provide evidence that the intrusions represent a single 1881 to 1886 Ma magmatic province that encompasses parts of the Flin Flon Belt and the south flank of the Kisseynew Domain.

The various Josland Lake-type sills intrude a variety of adjoining tectonic assemblages in the Flin Flon-Snow Lake-Kississing Lake region. The correlation of these sills suggests that, during the 1886 Ma magmatism, this region was part of a single composite terrane that included the Amisk collage. The sills are concentrated along the north and east margins of the Amisk collage, particularly in the upper sedimentary formation in the Fourmile Island assemblage (Yakymiw Formation of Bailes, 1980). They also occur in the upper sedimentary formation in the Snow Lake arc assemblage (Parisian Formation of Bailes, 1980), as well as in the intervening Northeast Reed ocean-floor assemblage. Similarly, the Mikanagan Lake sills intrude the upper part of a thick arc-rift volcanic succession (Bailes and Syme, 1989; Syme et al., 1999). Thus, the episode of sill intrusion represents an end stage in the early volcanism in the Flin Flon-Snow Lake region, during a period of basin development and basin-fill sedimentation. The similarity of the geochemistry of the chilled magma to that of E-MORB or arc-rift basalt suggests that the sill intrusion and sedimentation are the result of arc rifting. We conclude that this was a widespread event throughout the Flin Flon Belt and at least in parts of the Kisseynew Domain.

Early folds that deformed some Josland Lake sills were intruded along their axial planes by relatively young Josland Lake sills, including the one described herein and dated at 1886 Ma. This critical field relationship demonstrates that the folding overlapped the 1886 Ma episode of magmatism. All the sills were originally emplaced as horizontal sheets that became strongly differentiated and layered. Thus, the sills that occupy axial planes demonstrate that the folds were recumbent at the time of intrusion. This recumbent folding represents the earliest deformation documented to date in the Flin Flon Belt. We speculate that the recumbent structures and coeval sills may have been related to extensional collapse with vertical shortening of parts of the Glennie-Flin Flon Complex during the development of an arc-rift basin. Local recumbent folding has been reported from the margin of other extensional basins (Sharp et al., 2000).

The tectonic juxtaposition of various arc and back-arc assemblages with the Burntwood Group turbidite in the Reed Lake area has led to a model of renewed terrane accretion after 1.85 Ga turbidite sedimentation (Syme et al., 1995). This event

represents an early stage of the protracted continental collision tectonics that affected the area (Zwanzig, 1999). The tectonic model suggests that an ocean basin, which existed between Flin Flon and Snow Lake, was closed during the renewed accretion. The proposed arc rifting, accompanied by intrusion of Josland Lake sills, at 1886 Ma may have led to the opening of this early basin. The continuity of the structural slices of the Burntwood Group, the Josland Lake sills and their host volcanic assemblages, from Reed Lake into the Kiseynew Domain, suggests that the proposed arc-rift basin was part of an ancestral Kiseynew basin (an ocean of unknown size and shape). The basin probably closed during late successor-arc magmatism and the coeval deposition of the Burntwood and Missi groups, 40 m.y. after the initial rifting, and thus incorporated the younger sedimentary rocks into the expanding tectonic collage.

In light of the elevated PGE content of some of the sills (Peck et al., 2000), and the presence of gold deposits and showings in the felsic differentiate above the ferrogabbro (Zwanzig 1994; Zwanzig and Schledewitz, 1992), the proposed episode of widespread arc rifting ca. 1881 to 1886 Ma is important in understanding the distribution of precious metals in the region. Volcanic massive sulphide (VMS) deposits may have formed in the earliest stage of the arc rifting (Zwanzig and Bailes, work in progress, 2001), similar to other VMS deposits in the Flin Flon Belt that are associated with intra-arc extension (Syme et al., 1999).

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GS-4 PLATINUM-GROUP ELEMENT INVESTIGATIONS IN THE FLIN FLON GREENSTONE BELT: MCBRATNEY LAKE OCCURRENCE AND JOSLAND LAKE INTRUSION (PARTS OF NTS 63K/9, /13)

by P. Theyer



Theyer, P. 2001: Platinum-group element investigations in the Flin Flon greenstone belt: McBratney Lake occurrence and Josland Lake intrusion (parts of NTS 63K/9, /13); in Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey p. 33-39.

SUMMARY

The recently discovered McBratney Lake platinum-group element (PGE) occurrence, located approximately 7 km east of Flin Flon in the Flin Flon greenstone belt, highlighted the potential for 'contact-type' PGE mineralization that is assumed to be due, in this case, to the physical and chemical interaction between a mafic to intermediate magma and sulphide-bearing mafic volcanogenic host rocks.

Drilling by Fort Knox Gold Resources Inc. yielded a 16.8 m section of massive sulphide mineralization assaying a remarkable 8.9 g/t Pd, 1.8 g/t Pt, 1.1% Cu and 0.6% Ni; highest concentrations of 15.4 g/t Pd, 1.9 g/t Pt, 1.6% Cu and 1.2% Ni were encountered in a 7.3 m portion of this section.

Overburden stripping in 2001 exposed a structurally enhanced, massive-sulphide body that straddles the southern contact between a gabbroic lens and mafic volcanogenic rocks of the Bear Lake basaltic andesite suite. cursory prospecting of a segment of this contact in the vicinity of the McBratney Lake occurrence led to the discovery of two additional sulphide concentrations in a comparable geological environment. A third sulphide occurrence, known to contain significant PGE concentrations and also located at the contact between gabbro and the Bear Lake basaltic andesite (P. Lewis, pers. comm., 2001), suggests that this geological setting may yield further sulphide concentrations. The McBratney Lake PGE discovery is significant because of the exceptionally high PGE concentrations and because there may be significant potential for additional similar mineralization, due to the approximately 50 km long contact of the gabbro intrusive rocks with the Bear Lake basaltic andesite suite.

The Josland Lake intrusion is a layered, differentiated gabbroic body that intruded volcanic rocks of Early Proterozoic age in the vicinity of Snow Lake. The presence of PGE-enriched and -depleted domains in the Josland Lake intrusion suggests that economic PGE concentrations may have formed in this igneous body. Sulphide concentrations of up to 5% pyrrhotite were sampled at several localities within this differentiated body.

MCBRATNEY LAKE AND RELATED PGE OCCURRENCES

Part of the summer was spent investigating the McBratney Lake occurrence, located approximately 7 km east of the town of Flin Flon. A September 2000 press release by Fort Knox Gold Resources Inc. focused the attention of the exploration community on a new and significant PGE exploration project. This announcement reported an option agreement to explore a mineral prospect that Hudson Bay Exploration and Development Co. Ltd. (HBED) had originally drilled in 1991 and in which significant PGE and Ni-Cu concentrations were discovered. Fort Knox Gold redrilled this target, intersecting 16.8 m of massive-sulphide mineralization that returned 8.9 g/t Pd, 1.8 g/t Pt, 1.1% Cu and 0.6% Ni. This intersection included 7.3 metres that assayed 15.4 g/t Pd, 3.2 g/t Pt, 1.6% Cu, 1.2% Ni and 21.5 g/t Au. A magnetometer survey over the target area suggested that the mineralization is controlled by the intersection of a southwest-trending fault and the south-trending contact between the Big Island gabbro and the Bear Lake basaltic andesite suite. Fort Knox Gold continued exploration of this property in the summer of 2001 by stripping the target area of more than 8 m of glacial overburden and conducting geological mapping and channel sampling in the pit.

The author, in cooperation with Fort Knox Gold, mapped and sampled exposures in the pit and investigated the geology of comparable geological environments in the vicinity.

Geology

Volcanogenic massive-sulphide deposits in the Flin Flon metavolcanic belt occur, according to Syme and Bailes (1993), in an Early Proterozoic island-arc setting. North- to northeast-trending, postmetamorphic, brittle to ductile faults and shear zones subdivide the supracrustal rocks into tectonic blocks. The McBratney Lake occurrence is located in the arc-tholeiitic Bear Lake Block (Fig. GS-4-1). The Bear Lake Block is dominated by basaltic andesite, in a 3.3 km thick sequence of mafic volcanogenic rocks that includes aphyric to pyroxene-plagioclase-phyric lava flows, pillow-fragment breccias, synvolcanic dykes and sills, and minor interflow mafic tuff (Syme and Bailes, 1993). The volcanic rocks of the Bear Lake Block are intruded by a suite of gabbro, diorite and quartz diorite. These intrusions are parallel to the host-rock fabric and tend to have ovoid to elongate septae-like shapes with length to width ratios exceeding 1:100 in some instances. Bailes and Syme (1989) classified these rocks as 'Pre-Missil Intrusive rocks, intrusions of unknown age' and named one of the intrusions the 'Wonderland Lake gabbro' and its southern prolongation the 'We Lake sill' (Fig. GS-4-1).

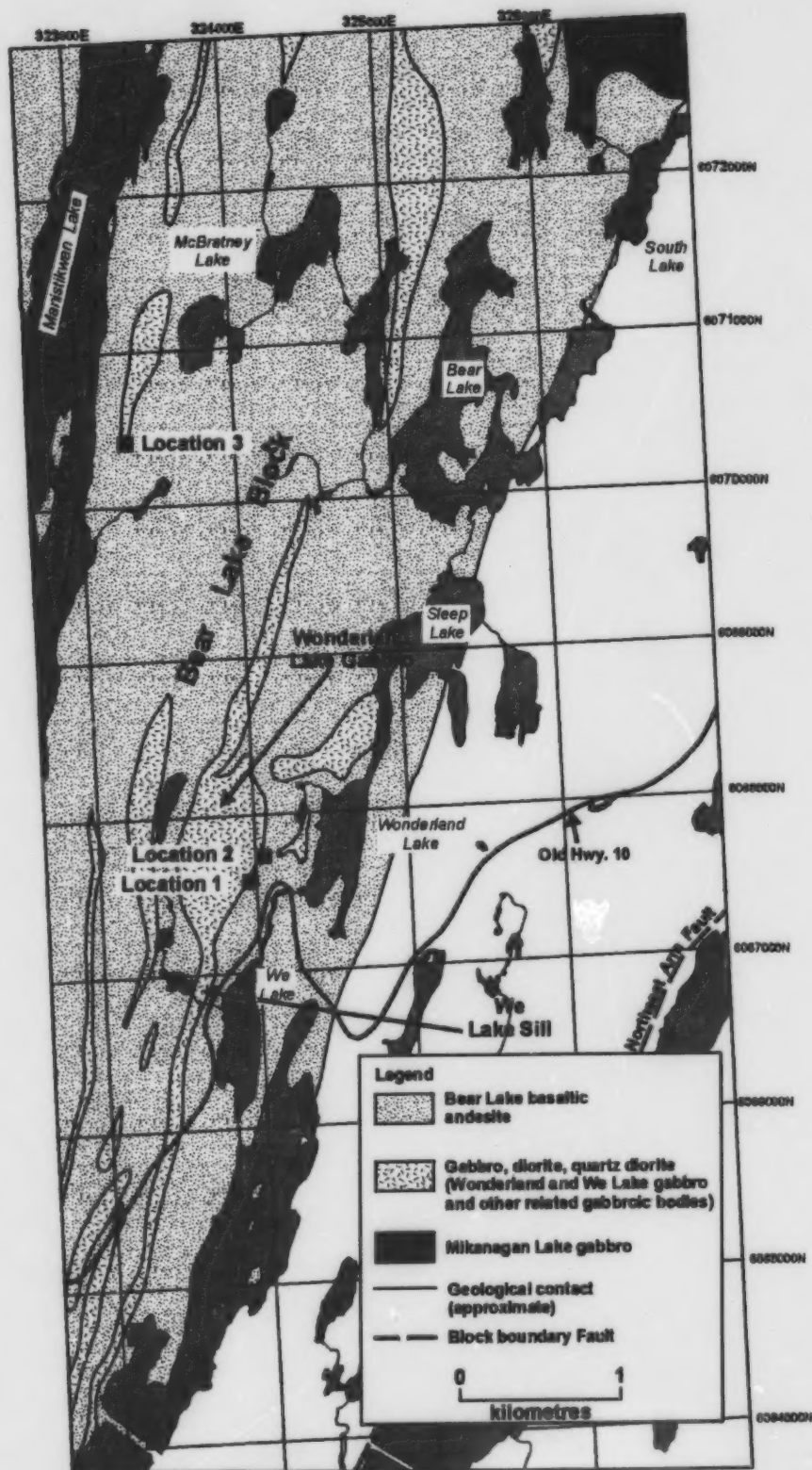


Figure GS-4-1: Simplified geology of the McBratney Lake occurrence and its vicinity, showing locations of the mineral occurrences discussed in the text.

A traverse across the thickest part of the Wonderland Lake gabbro displayed a well-differentiated igneous body consisting, from east to west, of gabbro grading, within approximately 10 m, into quartz diorite that constitutes the approximately 350 m thick bulk of this body. The western edge of this intrusive body consists of gabbro, which grades into peridotite that is at least 12 m thick. The transition from gabbro into peridotite is not consistent with the observations of Bailes and Syme (1989), who classified this peridotite as part of the Whitefish Lake intrusion, a multiphase mafic intrusion that also includes wehrlite and pyroxenite. The contact of the peridotite with Bear Lake basaltic andesite to the west (Bailes and Syme, 1989) was not observed in this traverse.

Mineral Occurrences

McBratney Lake occurrence

This sulphide occurrence is located at the southern end of a septum-like gabbroic intrusion (Fig. GS-4-1) that is interpreted as being related to the Wonderland Lake intrusion and the Bear Lake basaltic andesite suite. It is structurally controlled by the intersection of a southwest-trending fault and the south-striking contact between gabbro and basaltic andesite. This mineral occurrence, first drilled by HBED in 1991, was redrilled by Fort Knox Gold in 2000. In 2001, the occurrence was exposed by stripping approximately 9 m of glacial sediments (Fig. GS-4-2).

The McBratney Lake occurrence consists of a massive-sulphide body that was tectonically emplaced at the contact between gabbro and basaltic andesite. The sulphide mineralization is strongly banded, probably due to deformation that resulted in the separation of sulphide minerals of differing competence into centimetre-thick bands of varying compositions. Polished slabs display distinct bands of pyrrhotite, chalcopyrite, talnakhite and cubanite, as well as blebs of pentlandite. A metre-sized, vaguely defined domain of disseminated pyrrhotite, trending in a northerly direction, adjoins the massive sulphide accumulation.

The north-trending contact between the gabbro and basaltic andesite, exposed in the pit for approximately 8 m in a northerly direction, was tested by two channel samples. Sulphide concentrations in this segment were scarce, consisting of pyrrhotite that is concentrated mainly at the contact, and within centimetres of the contact, of the two rock units (Fig. GS-4-3).

Geological traverses in the vicinity of the pit showed that both the Bear Lake basaltic andesite suite and the gabbro are well exposed, and that almost ubiquitous rust staining characterizes most of the contacts. Outcrops of the Bear Lake suite, in the vicinity of the pit, contain sporadic occurrences of sulphide. At one locality, up to 10% coarse-grained pyrite occurs in a layered, aphanitic, basaltic rock that may have been an interflow sediment.

Kennel occurrence

Interest focused on the contact between the Bear Lake basaltic andesite and the gabbro intrusions, in view of the fact that the McBratney Lake sulphide occurrence is located at this contact.

The 'Kennel' occurrence is an analogous sulphide occurrence named after a kennel located at the side of a gravel road leading to the occurrence. Sulphide mineralization occurs on an approximately 35 m long section of the north-trending contact between the Wonderland Lake gabbro and the Bear Lake basaltic andesite (Fig. GS-4-1, location 2; Fig. GS-4-4).

This contact is exposed on the flanks and at the top of an approximately 20 m high escarpment. Pyrrhotite of highly variable tenor (trace to >40%) occurs over widths ranging from less than 1 cm to 40 cm. The sulphide minerals occur mainly within the basaltic andesite. Both the gabbro and the andesite show evidence of alteration, in the form of intense bleaching and chloritization of mafic minerals. Gabbro in the vicinity of the contact, is locally altered to an aphanitic, shaly fault gouge. Further evidence of intensive faulting consists of tectonically rounded basaltic-andesite fragments that were entrained in the fault gouge. Gabbro, at or near the contact with the Bear Lake suite, shows evidence of late brittle fracturing, concurrent with the circulation of fluids that



Figure GS-4-2: McBratney Lake pit, showing massive sulphide mineralization and thickness of glacial coverage.

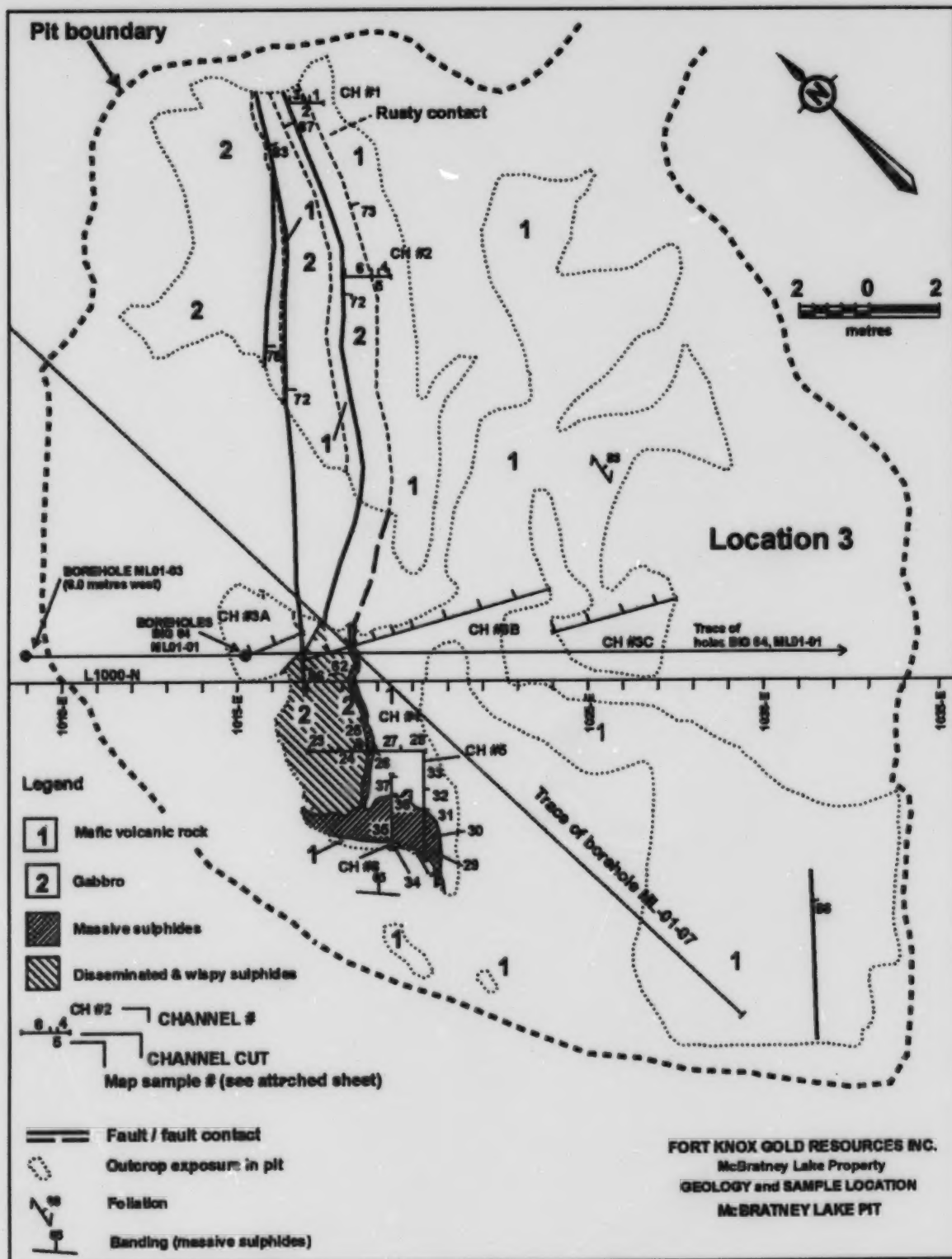
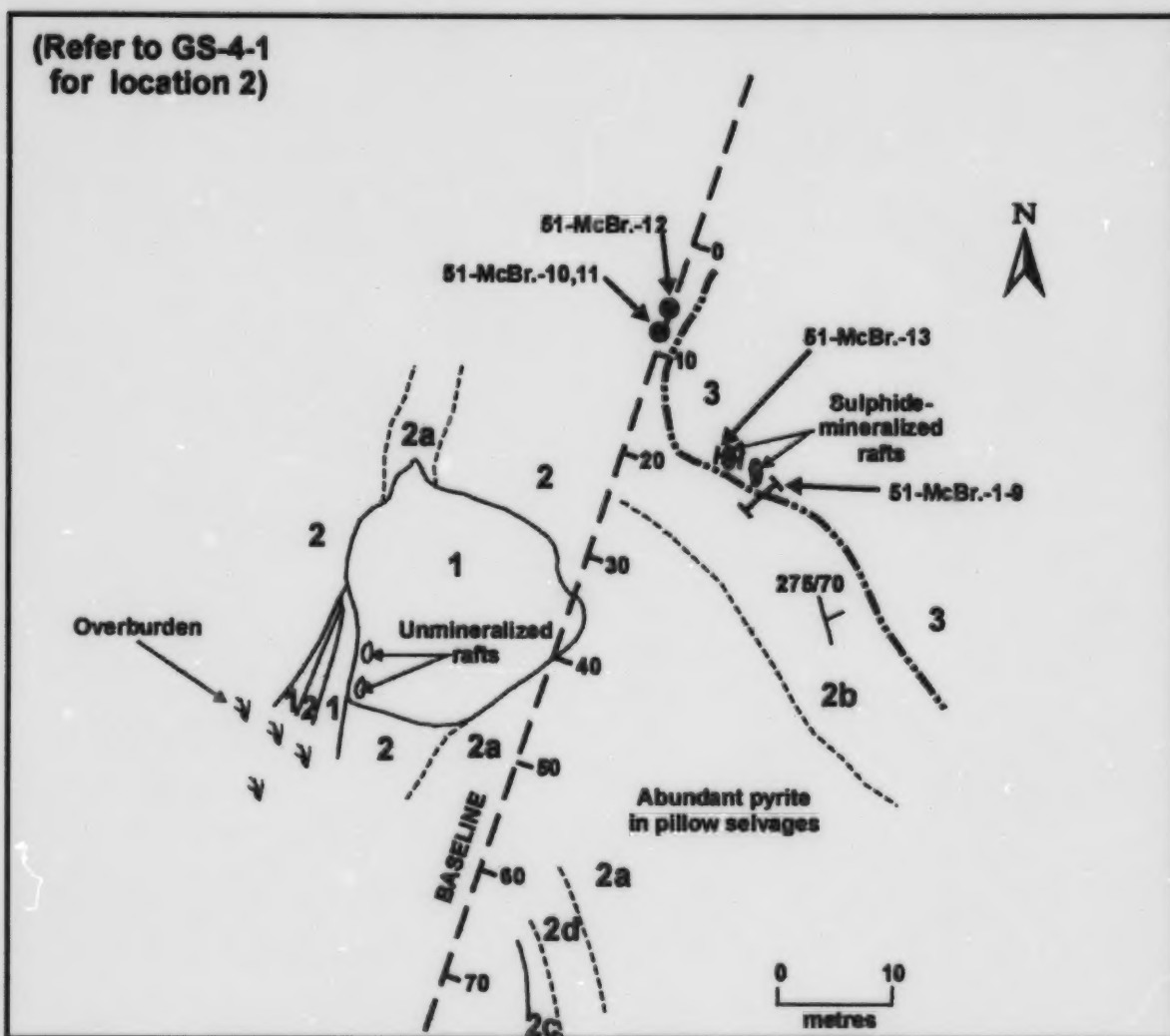


Figure GS-4-3: Geology of the pit at the McBratney Lake occurrence, showing the location and extent of channel samples (mapping by P. Lewis, 2001; published with permission of Fort Knox Gold Resources Inc.).

(Refer to GS-4-1
for location 2)



Legend

- 1** Granodiorite
- 2** Basalt
- 2a** Pillowed basalt
- 2b** Aphyric basalt
- 2c** Amygdaloidal basalt
- 2d** Mega-amygdaloidal basalt
- 3** Gabbro

Symbols

- Geological boundary (known, approximate)
- - - - - Geological boundary (approximate)
- 275/70
└─ Bedding (strike, dip)
- Sulphide mineralization
- ● Xenolithic rafts
- └─ Channel sample location

Figure GS-4-4: Geology of the 'Kenel' occurrence.

caused silica and carbonate ($\pm$ sulphide $\pm$ magnetite) mineralization.

Rocks in contact with gabbro are aphanitic massive basalt; however, in the vicinity of the contact, there occurs a variety of related rocks, such as pillowed basalt, amygdaloidal basalt and basalt layers with centimetre-sized gas cavities. Many pillows display centimetre-thick hyaloclastite rims that contain up to 3% pyrite.

Other mineral occurrences comparable to the Kennel occurrence

Geological prospecting along the margin of the gabbro intrusion, approximately 150 m west of and subparallel to the Wonderland Lake gabbro and the Bear Lake basaltic andesite suite, produced evidence of intense faulting, accompanied by mylonitization and brecciation. The author also discovered evidence of previous sampling at pyrrhotite concentrations located at the contact of these units. (Fig GS-4-1, location 3).

Another pyrrhotite occurrence in an analogous geological setting (i.e., at or near the contact between the Wonderland Lake gabbro and the Bear Lake basaltic andesite) is reported approximately 150 m south of the Kennel occurrence (P. Lewis, pers. comm., 2001). This occurrence was trenced and sampled in the search for Ni-Cu mineralization, but was not assayed for PGEs (Fig. GS-4-1, location 1; G. Gale, pers. comm., 2001).

JOSLAND LAKE INTRUSION

The Josland Lake intrusion is part of a suite of layered, well-differentiated bodies of tholeiitic gabbro and derived amphibolitic rocks that intruded Early Proterozoic volcanic rocks. The petrography of the Josland Lake gabbro was described in detail by Bailes (1980). The most recent publication on the geology of the Josland Lake gabbro is by Syme et al. 1995. Zwanzig et al. (GS-3, this volume) published a recently determined U-Pb zircon age for the Josland Lake sills of 1886 ± 3 Ma (95% confidence level). These sills, together with the $1881 \pm 3/-2$ Ma Mikanagan Lake sill near Flin Flon, are interpreted to be part of a major igneous province, linked to arc rifting, that intruded the Flin Flon belt at the close of juvenile-arc volcanism.

Following the suggestion of a colleague (Bailes, pers. comm., 2001) several days were spent investigating the Josland Lake layered intrusive body. Nearly continuous outcrops along an abandoned CN Rail right-of-way greatly facilitated sample collection in an easterly direction, starting at Krug Lake (Fig. GS-4-5).

Sample Descriptions

The rock types encountered on this traverse are comparable to units described by Syme et al. (1995). Ferrodiorite devoid of sulphide minerals occurs east of Krug Lake. An approximately 1 m wide mylonitized rock at the eastern edge of the depression approximately 170 m east of Krug Lake suggests that the contact between the ferrodiorite and the gabbro is a major fault. The outcrop consists of interlayered bands of gabbro and ferrodiorite, 1 to 5 cm thick, with several centimetre-thick quartzofeldspathic lenses that are characterized by graphic intergrowths of quartz and feldspar. A few aphanitic, glassy, centimetre-thick veins and lenses are interpreted to be ultramylonite. West of the tectonized outcrop, a megacrystic 'harrisitic' gabbro is characterized by centimetre-sized amphibole (after pyroxene) laths intergrown with plagioclase and sulphide-bearing domains. Exposed on an escarpment is a coarsely crystalline 'harrisitic' gabbro that contains up to 5% disseminated pyrrhotite. The tenor of the mineralization tends to be higher near faults, but domains of metre-sized disseminated sulphides have also been observed in localities several metres distant from faults.

Other zones of sulphide mineralization that were observed in the Josland Lake gabbro include

- medium-grained gabbro containing approximately 2% pyrrhotite as fracture fills, 185 m east of Krug Lake;
- very fine grained quartzofeldspathic rock containing 2% disseminated pyrrhotite, approximately 190 m east of Krug Lake;
- fine-grained homogeneous ferrogabbro containing approximately 1% disseminated pyrrhotite, 480 m east of Krug Lake; and
- fine- to medium-grained, inhomogeneous, dark grey- to black-weathering ferrogabbro containing up to 3% disseminated pyrrhotite; higher concentrations of pyrrhotite were observed as fracture fills approximately 950 m east of Krug Lake.

The balance of the outcrops of this sill along the CN Rail right-of-way, as far as 2.8 km east of Krug Lake, were investigated but were generally found to be devoid of significant sulphide occurrences.

Geochemistry

A review of the chemical database available in Peck et al. (2000) shows that samples of the Josland Lake gabbro collected by Bailes (1980) are characterized by zones of PGE enrichment and depletion. These data suggest that there is a possibility for economically viable PGE concentrations.

At the time of writing, none of the samples collected and discussed in this report had been analyzed.

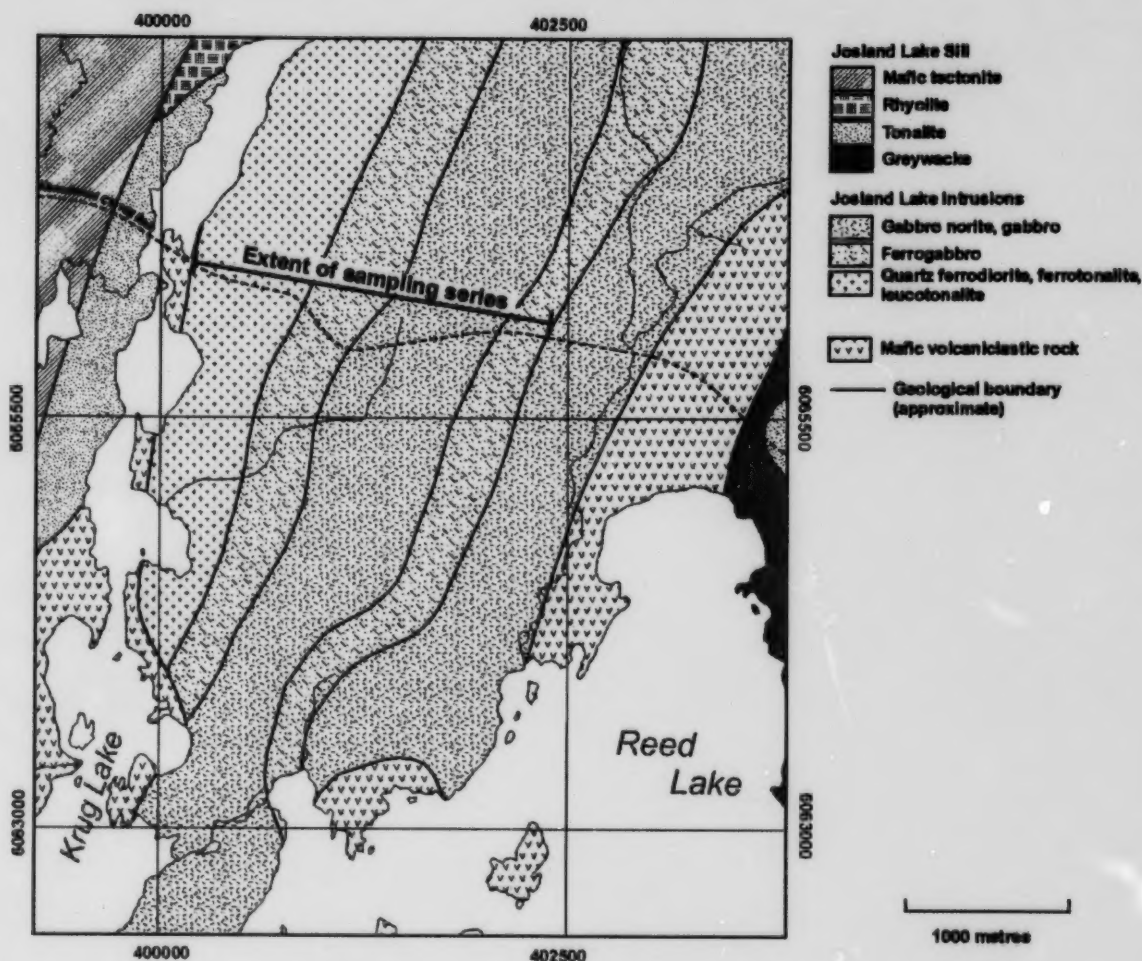


Figure GS-4-5: Location of the Josland Lake intrusion sampling traverse.

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Activities this year have been focused on completion of reports and maps relating to the Baker Patton project, ongoing studies of the New Britannia mine, and utilization of rare-earth elements (REE) as exploration tools for precious and base-metal deposits.

The 1:10 000 scale colour geological map of the Baker Patton Complex (BPC) has been completed. An accompanying geological report is in draft form and will be released as an open file in 2002. A separate report detailing the geochemistry of the Baker Patton area is in preparation, with most of the diagrams currently in draft format. Preliminary results of the geochemical study include the determination that these rocks are not of calc-alkaline affinity, as originally perceived (Bailes and Syme, 1989), but are transitional between tholeiitic and calc-alkaline affinities. This is important, as it indicates that these rocks have the potential to contain major volcanogenic massive-sulphide (VMS)-type deposits. This is based on the observation that host rocks for the Kuroko, Mt. Windsor and other massive-sulphide deposits have rare-earth values that plot in this transitional field (Lentz, 1998).

Major- and trace-element data have been used to effectively delineate the major zones of alteration present in the BPC. Alkali metasomatism is extensive in the BPC and includes seawater-rock alteration, hydrothermal activity associated with VMS-type mineralization, and calcium addition related to late brittle deformation (Fig. GS-5-1). Unfortunately alkali metasomatism does not provide a reliable indicator of VMS-type alteration. However, potassium alteration (Fig. GS-5-2) does appear to be predominantly associated with VMS-type mineralization. In addition, plots of alkali molar ratios (Fig. GS-5-3) illustrate the sites of intensely altered rocks, as portrayed by the presence of chlorite as an alteration phase. Figure GS-5-4, total Cu+Zn, shows elevated metal values in some intensely altered zones. The detailed mapping and geochemical data permit a re-evaluation of previous drill information and the delineation of new exploration targets in the BPC.

Frequent underground examinations of the New Britannia gold deposit at Snow Lake have been undertaken to document the geological setting of the deposit and characterize the nature and genesis of the mineralization. The mineralization and alteration associated with this deposit appear to predate regional deformation. To date, all faults recognized in the underground workings postdate deposition of the original mineralization, and structures such as the Howe Sound Fault have been shown to deform the mineralization. In addition, old level plans have been digitized in order to permit three-dimensional modelling of the geology.

Ongoing studies of drill core from the Snow Lake area indicate that REE data can be used to discriminate between barren sulphide mineralization not related to VMS deposits and metal-poor sulphide mineralization that is related to VMS deposits. The REE data can also assist in establishing vectors to VMS-type hydrothermal vent sites. Co-operative studies are being undertaken with several exploration companies to apply these REE techniques in the search for economic mineralization. Preliminary studies are being undertaken to investigate the applicability of REE data in the search for sediment-hosted exhalative-type precious-metal deposits.

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Feldspar

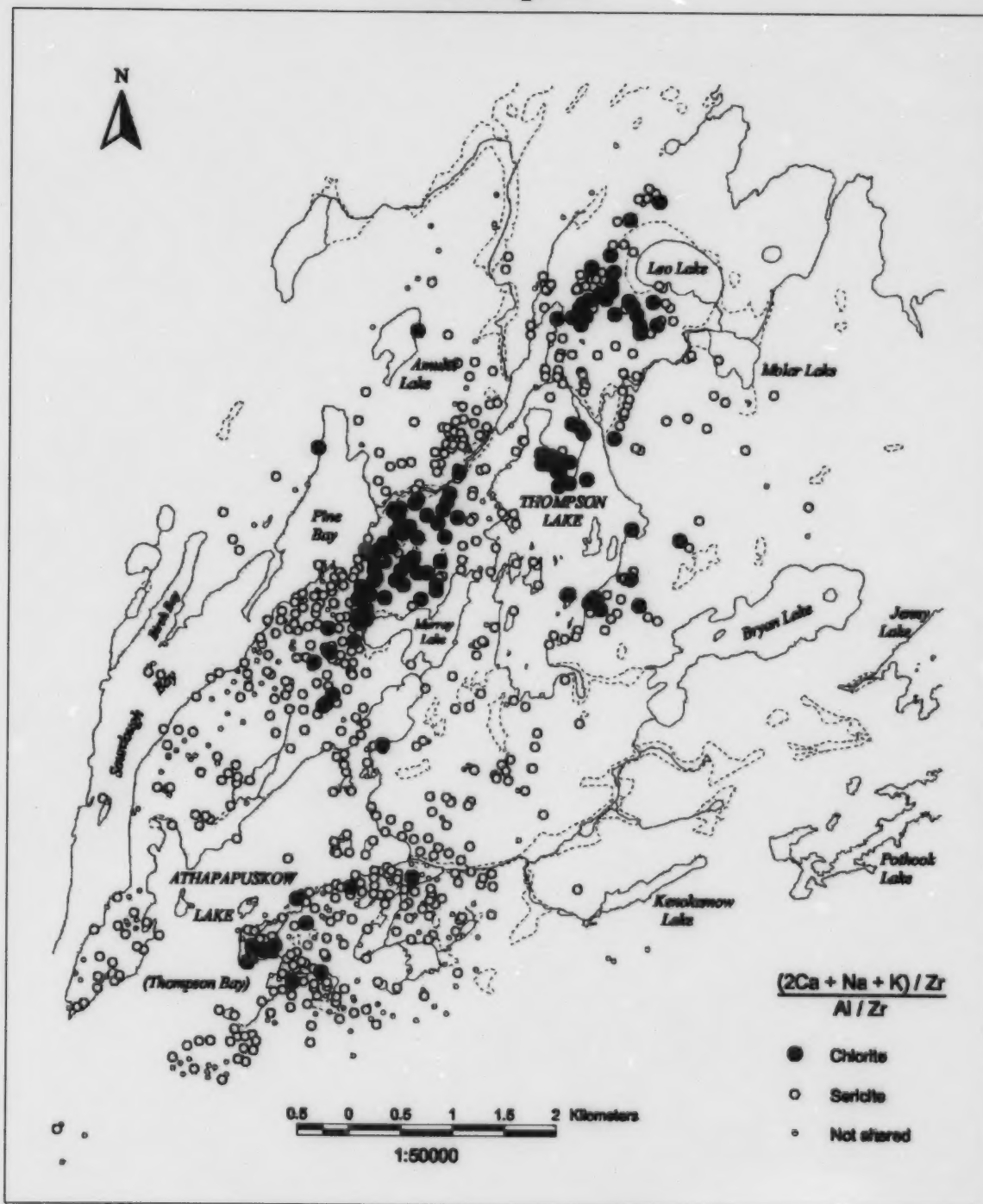


Figure GS-5-1: Alteration intensity for the Baker Patton Complex depicted by molar chlorite and sericite based on the ratio $[(2Ca+Na+K)/Zr]/(Al/Zr)$, after Madeisky and Stanley (1993). Ratios near or >1 commonly indicate nonaltered rocks.

Potassium

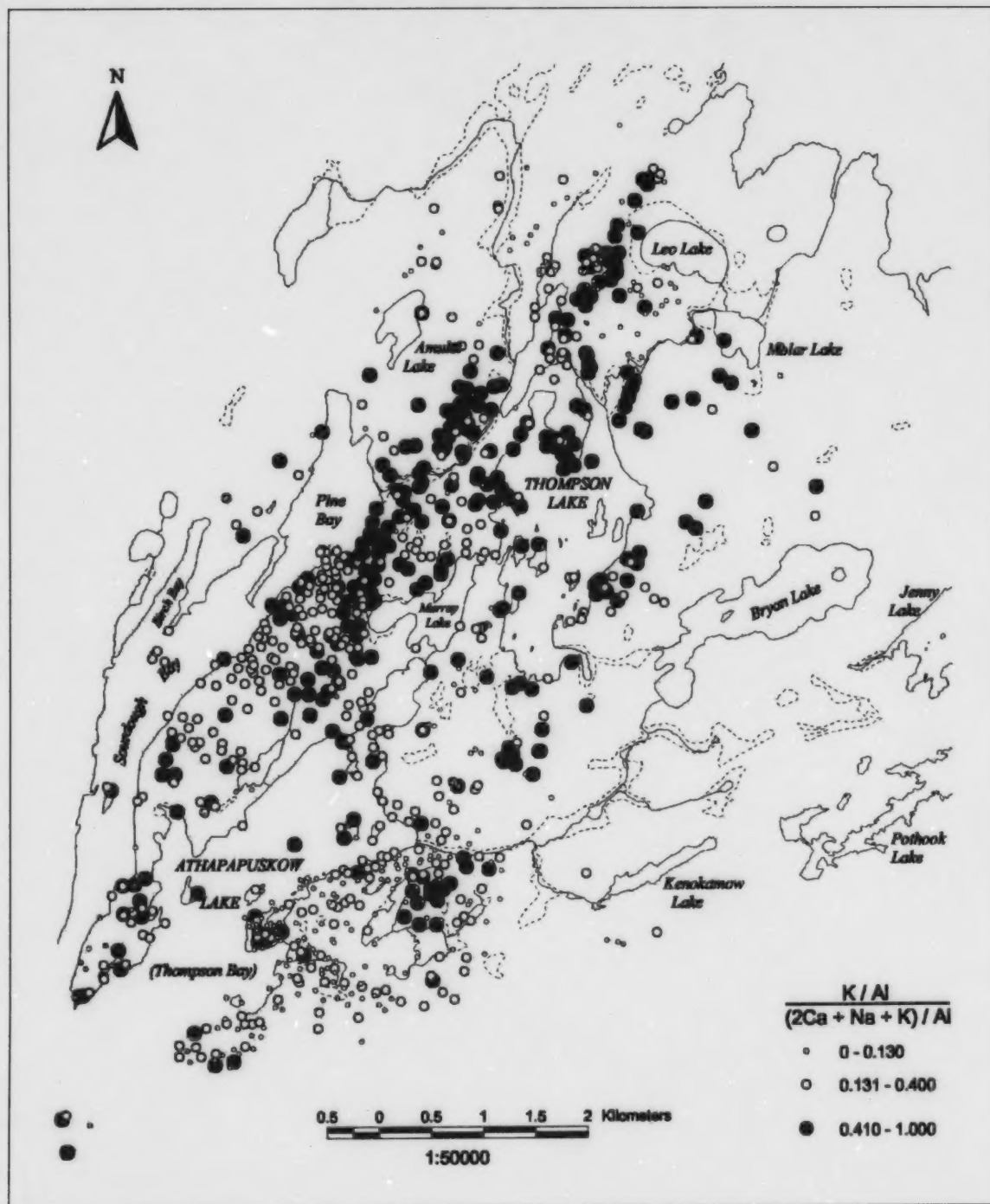


Figure GS-5-2: Potassium Number diagram for the Baker Patton Complex. This is a molar ratio $(K/Al)/[(2Ca+Na+K)/Al]$ that portrays the extent of potassium metasomatism (after Stanley and Madeisky, 1994).

Alkali

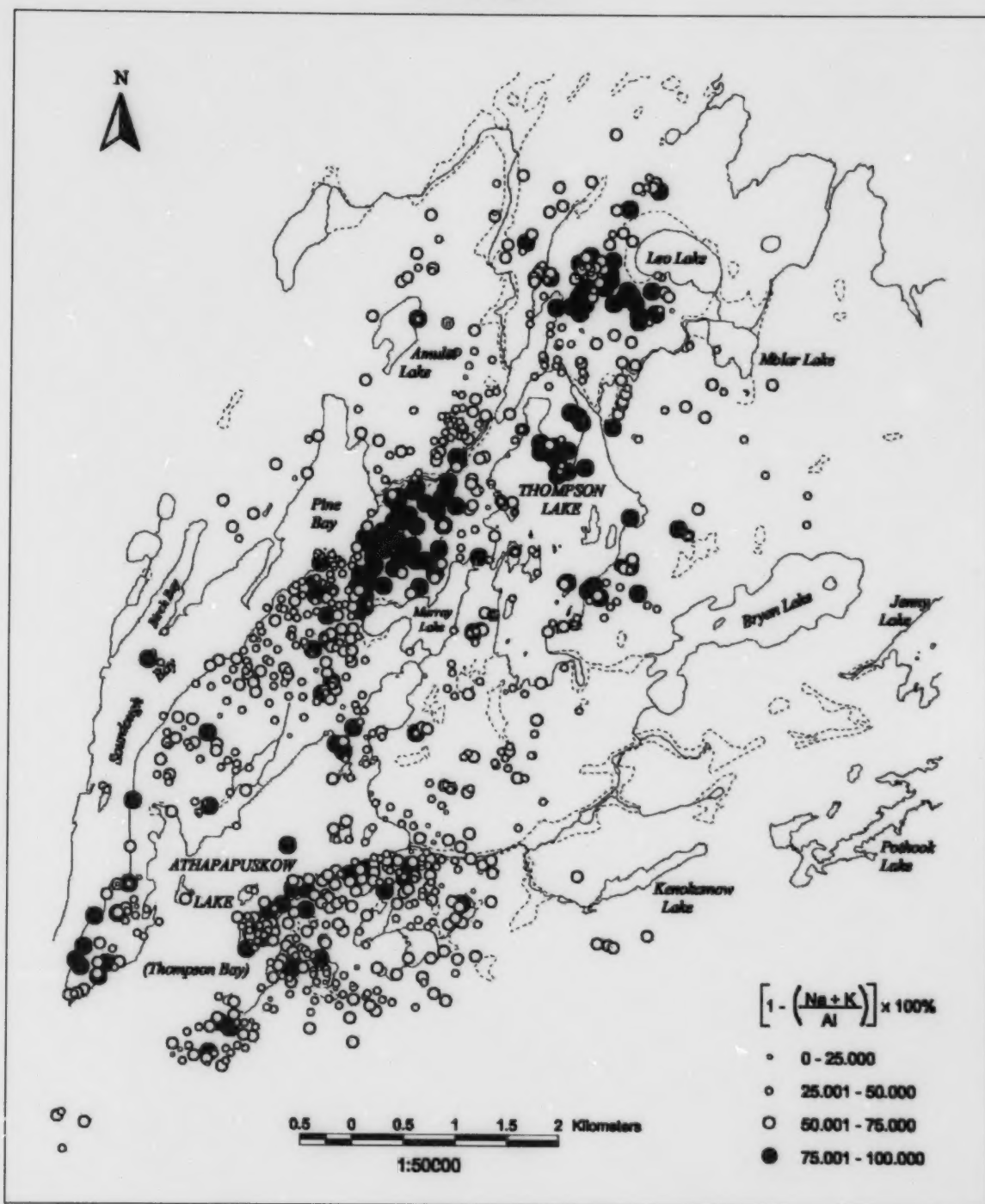


Figure GS-5-3: Alkali alteration index for the Baker Patton Complex, based on molar ratios $\left[1 - \frac{(Na+K)}{Al}\right] \times 100$. This diagram helps to negate the effects of Ca metasomatism in felsic rocks (after Madeisky, 1995).

Cu + Zn (ppm)

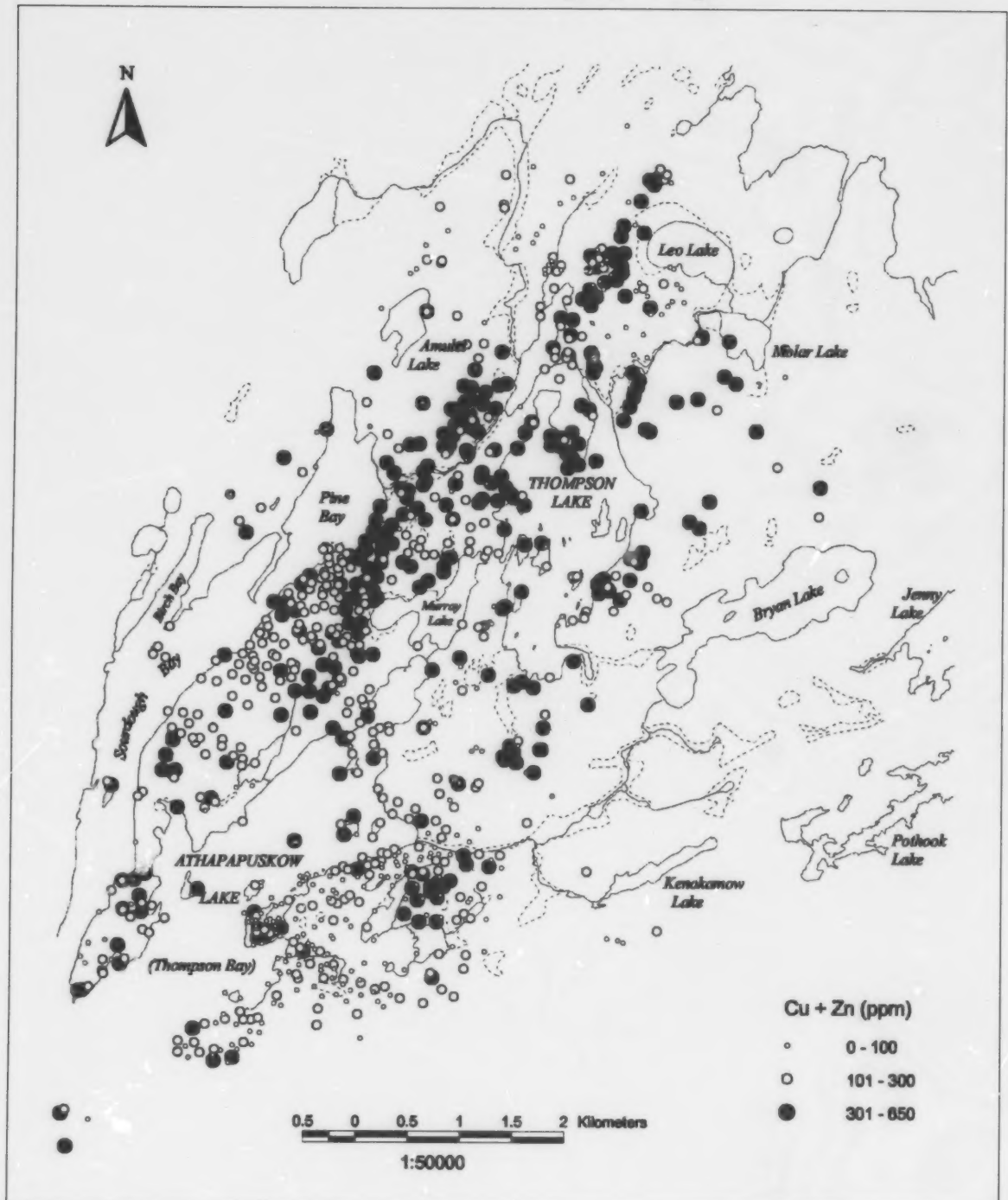


Figure GS-5-4: Total Cu+Zn for rocks of the Baker Patton Complex.

Heine, T.H. and Prouse, D.E. 2001: Activities of the Flin Flon regional office; in Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 45-46.



SUMMARY

The Flin Flon office continues to provide assistance to the mineral-exploration and mining communities in the Flin Flon-Snow Lake region. This includes recording new mineral claims, maintaining an up-to-date library of provincial claim and land-status maps, dealing with claim-status inquiries and accepting assessment-work submissions. The present staff includes a Regional Geologist (Heine) and a Resident Geologist (Prouse). A Mining Claims Inspector will be transferred from The Pas to Flin Flon once office space is found in the Barrow Provincial Building. Assistance was provided for several research projects being undertaken in the region. An inventory is in preparation of the core repository at the Centennial mine site and all core piles have been reorganized and stabilized. The mine documentation project is proceeding with the addition of new ore samples from a number of now-closed mines and the establishment of a database for the core repository at the Stall Lake mine near Snow Lake.

MINING RECORDING

Mining recording and associated responsibilities are now the responsibility of the Regional and Resident geologists. An up-to-date collection of claim and land-status maps for the Province of Manitoba is maintained for public reference, applications for new claims are recorded, and assessment reports are accepted by the Flin Flon office. Reports summarizing the status and history of specific claims are prepared for clients when requested. Submission of other applications that fall under the Mines Act (e.g. casual quarry permits, prospecting licenses) are also processed by the Flin Flon office.

EXPLORATION AND RESEARCH ASSISTANCE

The main function of the Flin Flon office continues to be providing assistance to the mining and mineral-exploration communities, and all clients interested in the geology of the region. Access to the Precambrian Drill Core Libraries, located in The Pas, Thompson and Lynn Lake, is given to clients through this office. A secure exterior core-storage area is available adjacent to the Centennial core-viewing facility for clients who wish to protect their core from vandalism or loss. Some funding was made available for core recovery and collection maintenance, and up-to-date inventories of the libraries and the Centennial site are in preparation (Prouse, GS-28, this volume). Core stored in the Centennial site compound was reorganized and stabilized this summer.

Logistical and technical support was provided to several summer field projects undertaken in the region, including the federal-provincial Flin Flon Targeted Geoscience Initiative (TGI), and geological tours and collecting expeditions with Ronald Frost and Susan Bragg (University of Wyoming).

This office has been involved in providing technical support for the Green Project, a local initiative to ameliorate the acidic soil conditions and promote plant growth in areas affected by SO_2 discharge from the Flin Flon smelter. These efforts are under the direction of David Price (Daprock Enterprises). Crushed dolomitic limestone is being manually spread in selected areas, mainly by local school groups. To date, the results of this project have been very encouraging.

An invitation from Manitoba Conservation to sit on a regional advisory committee focusing on the management of woodland caribou in west-central Manitoba has been accepted. This will provide geological input into areas that may be considered for exclusion from mineral exploration or development.

REPORTS

The *Mineral Deposit Series* report for Iskwasum Lake (63K/10) has been reviewed and will be published before fiscal year-end. The report for Elbow Lake (63K/15) is written and will be reviewed and published by the summer of 2002.

The activities of the mining and mineral-exploration communities within Manitoba were actively monitored, and summary reports prepared for both internal use and external publication.

MINE DOCUMENTATION PROJECT

The mine documentation project, outlined in last year's *Report of Activities* (Heine and Prouse, 2000), continues to move forward. Hudson Bay Exploration and Development Co. Ltd. (HBED) has continued their support for this project, and has supplied plan and section maps for the Lost and Ghost mines in the Chisel Lake area, near Snow Lake. These are currently being digitized for inclusion in the mine database.

HBED supplied an inventory of their exploration-core repository on the abandoned railbed at the Stall Lake mine site in

Snow Lake. A database of this information has been created to facilitate the location and collection of core samples for inclusion in the mine-sample archive.

A collection of relatively fresh representative ore samples from a number of past-producing mines was obtained from Neil Provins (Falconbridge (Australia) Pty. Limited). These are currently being catalogued, and will be slabbed, polished and added to the archive suite.

Ian Jonasson (Geological Survey of Canada) is currently undertaking trace-element investigations on sulphides from volcanogenic massive-sulphide deposits. He has sample suites from a number of now-closed mines in the area, and these could be made available for our collection.

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SUMMARY

Work on a new compilation map of the Thompson Nickel Belt (TNB) continued during the fall and winter of 2000 and spring of 2001. The compilation map is a collaborative project involving the Manitoba Geological Survey, Inco Limited, Falconbridge Limited and Hudson Bay Exploration and Development Company Limited (HBED). New data, obtained from relogging of diamond-drill core during the summer of 2000 (Macek et al., 2000), and the results of remapping (Zwanzig, 1998; Zwanzig, 1999) have been included in the new map.

A preliminary version of the new compilation map, released on June 15, is available as a set of fifteen maps (Thompson Nickel Belt Geology Working Group, 2001a-o) that covers an area from Moak Lake (northeast of Thompson) to Bracken Lake (north of Grand Rapids). These maps represent preliminary results of the compilation effort and will ultimately be superseded by the final maps.

Another portion of diamond-drill core, from a southern part of the exposed TNB and presently stored in Wabowden, was re-examined during the summer of 2001. Data obtained will be incorporated into the final version of the TNB compilation map.

PRELIMINARY TNB COMPILATION MAPS

Fifteen preliminary compilation maps were issued in four groups (Fig. GS-7-1):

- The northern part of the exposed TNB (from Moak Lake area to Setting Lake) is covered by four maps designated I-1 to I-4.
- The southern part of the exposed TNB (from Setting Lake to Clarke Lake area) is covered by four maps designated FN-1 to FN-4.
- The northern part of the sub-Paleozoic portion of the TNB (from Ponton to Hargrave River-Hill Lake area) is covered by two maps designated HB-1 and HB-2.
- The southern part of the sub-Paleozoic portion of the TNB (from Hargrave River-Hill Lake area to Bracken Lake area) is covered by five maps designated FS-1 to FS-5.

The maps were issued at either 1:100 000 or 1: 50 000 scale, depending on the density of the data available. The latter versions usually display the Oswagan Group supracrustal sequence divided into five formations (Manasan, Thompson, Pipe, Setting and Bah Lake) and, where density of data permits, each formation is subdivided into several members. In addition, Kisseynew paragneiss is divided into Grass River and Burntwood groups and, where data permit, further subdivision into informal formations is made.

Two significant findings are apparent from the maps:

- Over twenty new occurrences of the Oswagan Group supracrustal sequence appear on the new compilation map, compared to the 1972 compilation map (Coates et al., 1972).
- All economic nickel deposits found to date are hosted by the Oswagan Group sequence.

RE-EXAMINATION OF THE DIAMOND-DRILL CORE

Re-examination of the diamond-drill core continued this summer (327 holes). Most of the core came from holes randomly distributed thorough the broad area around Wabowden, which straddles Phillips, Halfway, Setting, Bowden, Rock Island, Resting, Conlin, Gormley, Key and Muningwari lakes. To date, two-thirds of this core have been examined. Relogging of the rest of the core will be attempted next summer. Results from this summer and the next will be incorporated into the final version of the TNB compilation map.

RESULTS

A variety of ultramafic rocks, such as serpentinized dunite, metaperidotite, metapyroxenite, porphyroblastic metapicrite and derived ultramafic schist, was identified in 54% of the examined holes (Fig. GS-7-2a). Oswagan Group rocks were identified in 47% of the relogged holes (Fig. GS-7-2b). The frequency with which all Oswagan Group formations were intersected is shown in Figure GS-7-2c, where M, T, P, S and B stand for Manasan, Thompson, Pipe and Setting formations, and Bah assemblage, respectively. Results are comparable to those reported in Macek et al. (2000).

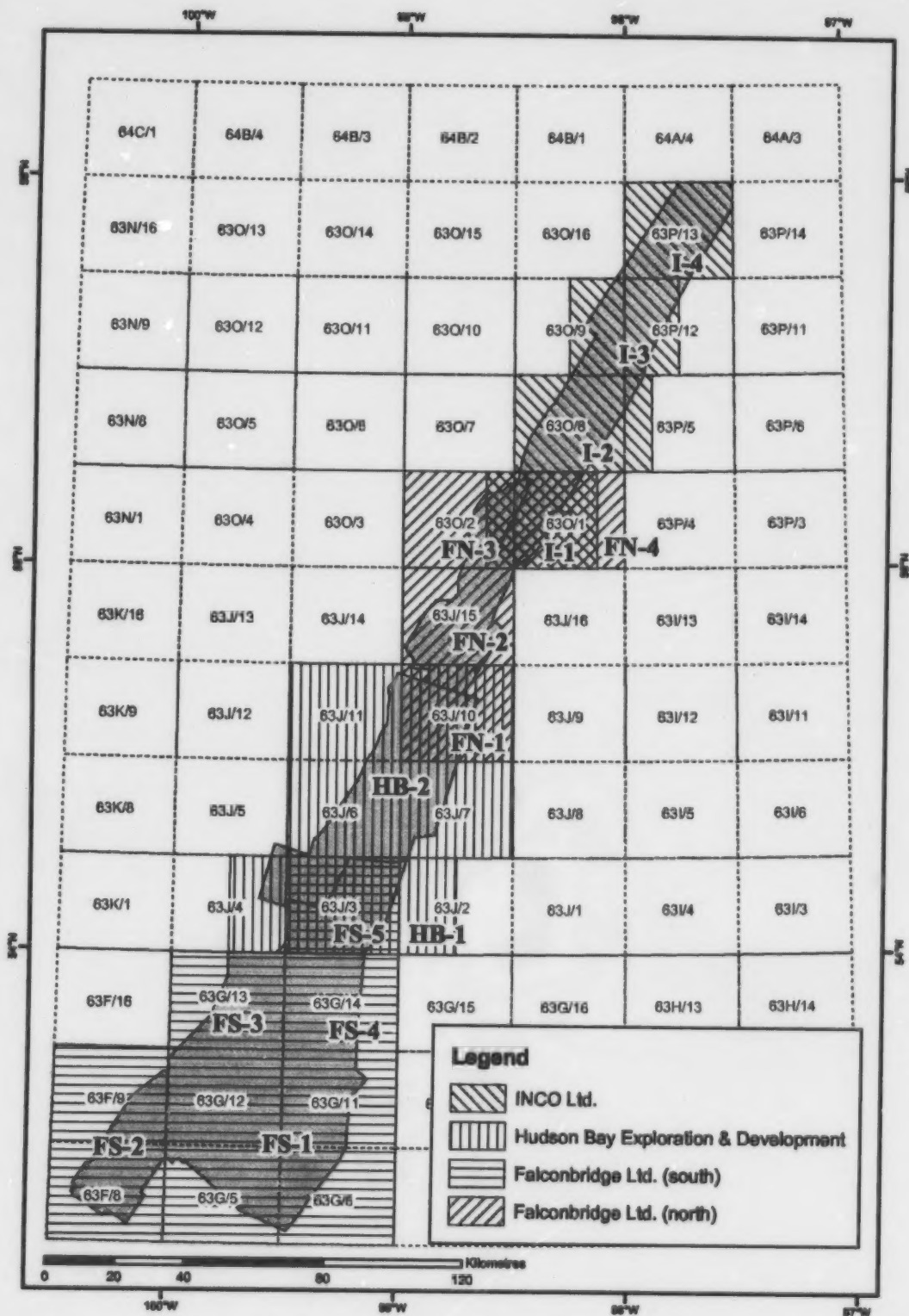


Figure GS-7-1: Map index for 2001 Thompson Nickel Belt compilation map.

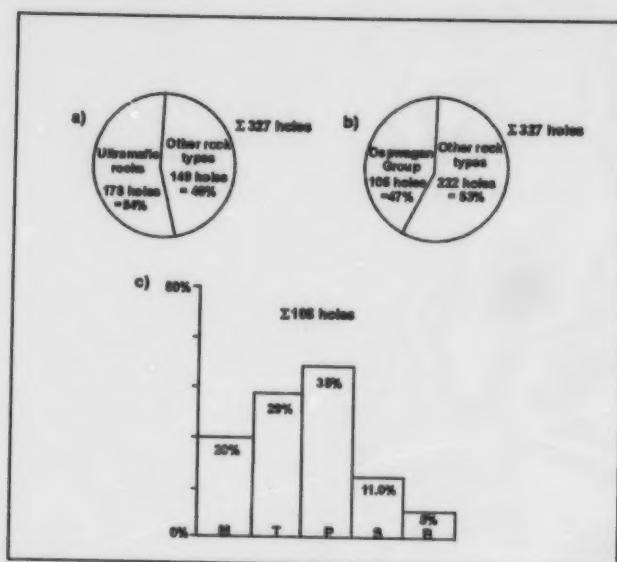


Figure GS-7-2: Main rock types encountered in the re-examined diamond-drill holes in the region around Wabowden: a) ultramafic versus other rock types, b) Ospwagan Group versus other rock types, and c) Ospwagan Group formations.

OUTLOOK

Within the next three- to four-year period, the recently issued preliminary compilation maps will be finalized. The final maps will be improved as follows:

- Geological and geographic data will be transformed onto the newest topographic base utilizing the orthophoto coverage.
- All features will be geographic information system (GIS) compatible.
- Boundaries among all four map subsets will be revised and made seamless.
- Structural information and a cultural infrastructure will be added.
- Maps will be accompanied by marginal notes.

ACKNOWLEDGMENTS

Once again, the authors gratefully acknowledge the generous logistical and personnel support of Falconbridge Limited, including free access to proprietary data; without this assistance, the compilation work would not have been possible.

We also thank our summer assistants, C. Lettley, K. Robinson, D. Heasman, C. Coueslan, J. Etcheverry and F. McGregor, for their valuable assistance and meticulous work conducted under difficult conditions.

Special thanks go to P. Lenton for the extraordinary effort necessary to issue all preliminary maps simultaneously and on time.

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**GS-8 SUPERIOR BOUNDARY ZONE-REINDEER ZONE TRANSITION IN THE PEARSON
LAKE-ODEI RIVER-MYSTERY LAKE REGION (PARTS OF NTS 63P AND 64O)**

by H.V. Zwanzig, Ch.O. Böhm¹ and J. Etcheverry²

Zwanzig, H.V., Böhm, Ch.O. and Etcheverry, J. 2001: Superior Boundary Zone-Reindeer Zone transition in the Pearson Lake-Odei River-Mystery Lake region; in Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 51-56.



SUMMARY

A new project was started to document the geological relations and isotopic ages of rocks north of Thompson, along the complex boundary zone between the northwestern Superior craton and the Trans-Hudson Orogen. Work proceeded on a 60 km transect, northeast from Thompson to Pearson Lake along the eastern part of the project area, that will extend west to Leftrook Lake. This summer, the major unit mapped as paragneiss of the Sickle Group on Pearson Lake was reinterpreted to comprise granodioritic orthogneiss with sheets of amphibolite (dykes and xenoliths) and minor magnetite-bearing paragneiss of unknown affinity. The main unit south of Pearson Lake is greywacke-derived migmatite similar to the Paleoproterozoic Burntwood Group. Abundant large samples of fresh rock were collected in this poorly accessible area for a variety of laboratory studies, including Sm-Nd isotope work and U-Pb age determinations to be conducted by Ch.O. Böhm at the University of Alberta.

Relogging and sampling of company-owned drill core from an area northwest of Mystery Lake was carried out with the co-operation and assistance of Inco Technical Services Limited and Nuinsco Resources Limited. This work will provide vital information from the largely muskeg-covered northernmost part of the Thompson Nickel Belt to help to trace its full extent. Samples were taken for petrographic, geochemical and geochronological studies (Sm-Nd isotopes and U-Pb ages).

Detailed mapping and sampling of a small area north of Thompson will elucidate the contact relation between the Mystery Lake granodiorite and what is interpreted as part of the Ospwagan Group (P3 member, Pipe Formation). Uranium-lead geochronology may provide an age of intrusion and deformation.

INTRODUCTION

A collaborative project of structural mapping, exploration drill-core re-examination, petrography, geochemistry and isotopic dating of a variety of gneissic rocks north of Thompson was started this summer by the Manitoba Geological Survey and the University of Alberta Radiogenic Isotope Facility in Edmonton, in co-operation with Inco Technical Services Limited and Nuinsco Resources Limited. This three-year project aims to help delineate:

- the northwestern extension of the Thompson Nickel Belt;
- the probable westward extension of early Archean gneiss;
- the apparent northeast termination of the juvenile Paleoproterozoic Kiseeynew paragneiss; and
- the southeastern boundary of Paleoproterozoic orthogneiss.

The collection and analysis of surface samples and company-owned drill-core samples are important aspects of the project. During this summer, work on a northeast transect across the project area involved:

- structural mapping and sampling of the shoreline of Pearson Lake, 60 km northeast of Thompson;
- re-examination and sampling of exploration drill core from the area west of Mystery Lake; and
- detailed mapping and sampling of several critical outcrops on the Burntwood River near Thompson (work leading to an undergraduate thesis for J. Etcheverry at the University of Manitoba).

In subsequent years, the work will be extended further west to encompass the Thompson-Pearson Lake-Leftrook Lake area. We intend to document the petrography, stratigraphy, major- and trace-element geochemistry, Sm-Nd isotope geochemistry and U-Pb geochronology of the gneiss units. The interpretation of these data will help to establish the geological framework and mineral potential of the area by characterizing and mapping the extent of the tectonic domains.

GENERAL GEOLOGY

The project area lies between Thompson and points 70 km to the northeast and 70 km to the northwest. It is largely covered by muskeg and clay, which overlie poorly understood Archean and Proterozoic bedrock along the northwestern boundary zone of the Superior craton and the southeastern boundary of the internal zone (Reindeer Zone) of the Trans-Hudson Orogen. The geology, compiled from shoreline exposures on the relatively small lakes and scattered inland outcrops in the area, features four or five tectonic domains of amphibolite facies gneiss (Fig. GS-8-1). A preliminary compilation, based on age and metamorphic history (Böhm et al., 2000; Corkery et al., 1999), indicates that the number, character, boundaries and

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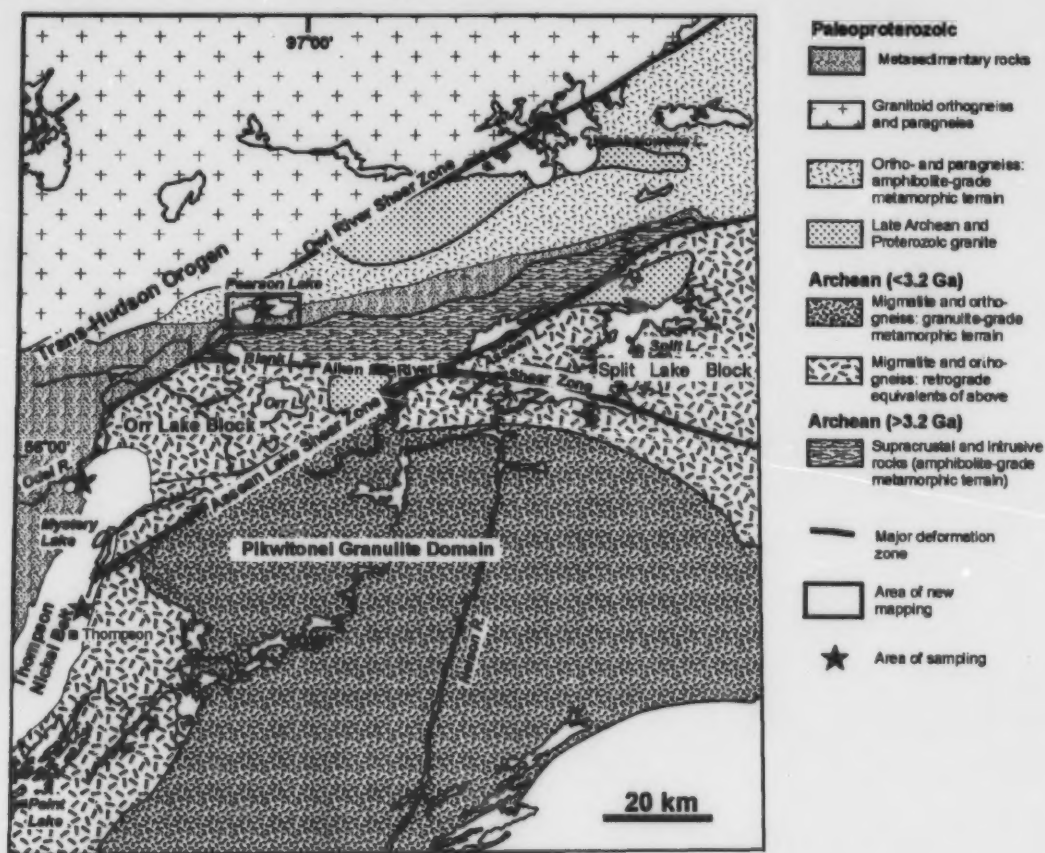


Figure GS-8-1: Simplified geology of the northwestern Superior craton boundary zone and the southeastern boundary of the Trans-Hudson Orogen, showing new areas of mapping and sampling.

tectonic origin of these domains are uncertain, but the tectonic architecture can be simplified to include, from south to north:

- 1) Thompson Nickel Belt (TNB), consisting of Archean basement rocks (partly retrograde from granulite facies gneiss) with infolds of early Paleoproterozoic supracrustal rocks (Ospwagan Group) and ultramafic to felsic intrusions;
- 2) Orr Lake Block, similar to TNB basement gneiss but in which the Ospwagan Group has not been confirmed by surface mapping;
- 3) Early Archean (≥ 3.2 Ga) orthogneiss and paragneiss (Clay River and Lindal Bay metagreywacke units; Böhm et al., 2000);
- 4) Kisseynew paragneiss (Burntwood Group metagreywacke and Sickie Group meta-arenite) and granitoid intrusive rocks of the largely juvenile Paleoproterozoic Reindeer Zone; and
- 5) Paleoproterozoic orthogneiss (foliated intrusive rocks of the Reindeer Zone) and local supracrustal enclaves.

The geology of the TNB, recently compiled on 1:50 000 and 1:100 000 scale maps (Thompson Nickel Belt Geology Working Group, 2001), indicates that the Ospwagan Group extends northwest of Mystery Lake, probably to the Odei River, but the limits of the belt are not defined (Fig. GS-8-2). Earlier mapping has indicated that the area northwest of Mystery Lake is underlain by Kisseynew gneiss, which extends northeast to Pearson Lake and northwest beyond Leftrook Lake (Lenton and Corkery, 1981; Manitoba Energy and Mines, 1991, 1995; Corkery et al., 1985). However, similar rocks farther east, at Assean Lake, include pre-3.2 Ga units in 3.1 to 3.2 Ga crust that extends west to Blank Lake, only 4 km south of Pearson Lake (Böhm et al., 2000; unpublished data). The full areal extent of the early Archean crustal block and the TNB are presently unknown. Surface mapping of these poorly exposed rocks has proven to be inadequate for distinguishing even the major crustal blocks. Samarium-neodymium isotope geochemistry model ages and high-precision U-Pb geochronological techniques are required to fully define exposed geological units north of Thompson. Additionally, samples are required from exploration drilling to characterize buried units. Other techniques, using geophysics, petrography, geochemistry and structure, will help in delineating the general geology in more detail.

PEARSON LAKE AREA

Shoreline exposures were remapped on Pearson Lake. Based on field observations, the rocks on the north shore and on

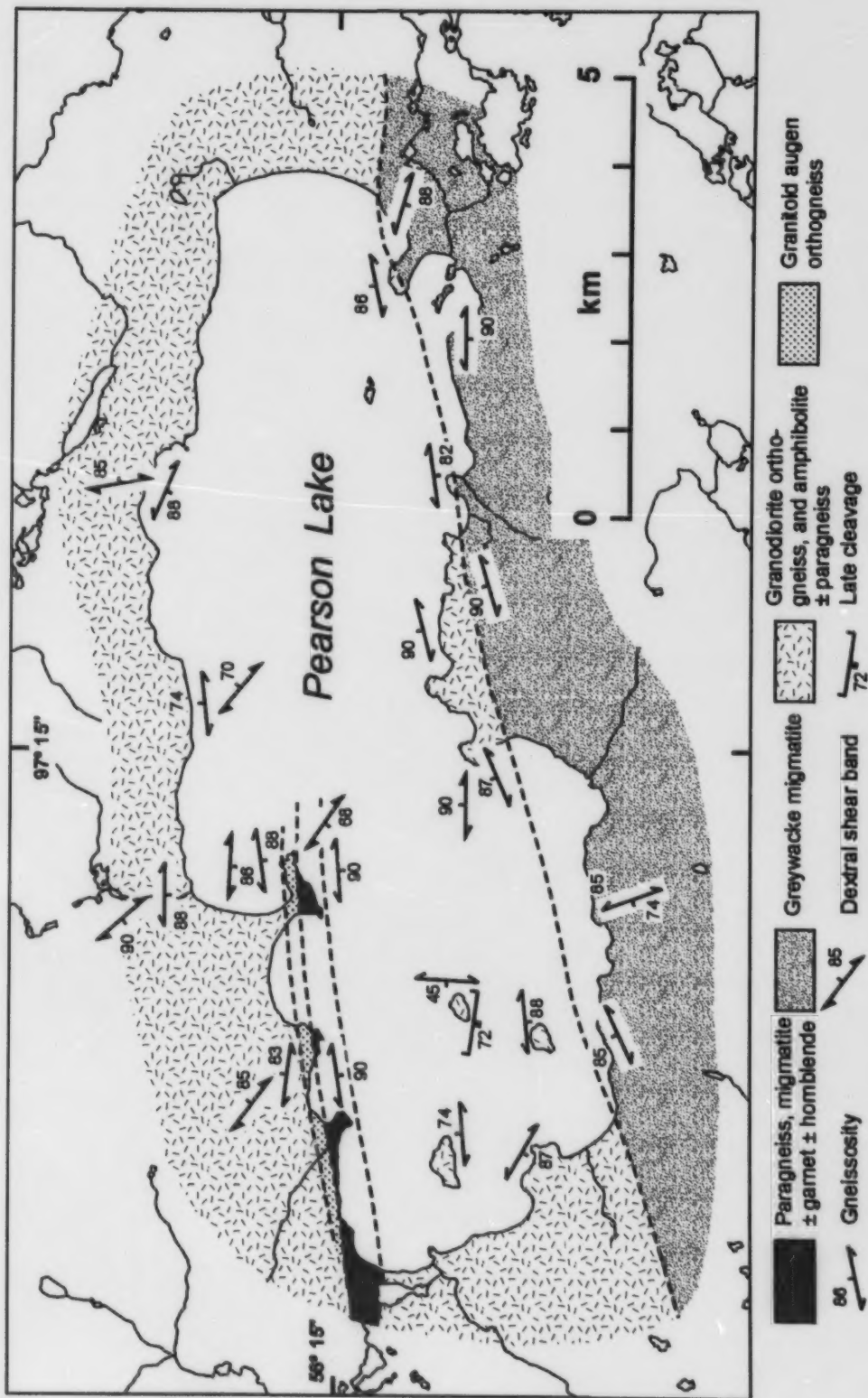


Figure GS-8-2: Geology of the Pearson Lake area.

several islands, previously mapped as paragneiss of the Sickie Group³ (Lenton and Corkery, 1981), were reinterpreted as orthogneiss with only minor units of paragneiss. Migmatized greywacke encountered on the south shore of Pearson Lake had been mapped previously as Burntwood Group³ (Lenton and Corkery, 1981). However, the age of the metagreywacke is uncertain because similar rock to the east, on Assean Lake, is early Archean (Böhm et al., 2000).

Granodiorite Gneiss

Orthogneiss is best exposed on the western part of the north shore of Pearson Lake. Its most widespread composition is quartz-rich granodiorite or granite, comprising predominantly pale pink- and white-weathering feldspar and grey quartz (approx. 40%). The granodiorite gneiss has a fine- to medium-grained component with approximately 8% biotite±hornblende and a subequal component of medium-grained leucosome in 1 to 50 cm thick layers with less than 5% biotite; contacts are rarely sharp between these components. In many places, approximately 10% of the rock consists of more sharply defined pegmatite veins and dykes that cut the gneissic layering at a low angle. Narrow screens of magnetite±hornblende-bearing or garnet-bearing paragneiss occur locally, but much of the granodiorite gneiss contains magnetite+biotite-rich schlieren that may represent remnants of paragneiss after partial melting. A fourth component in the orthogneiss is mafic, grading from rare hornblende-rich amphibolite and common gabbroic or fine-grained amphibolite to schlieric hornblende granodiorite. Various field relationships indicate that there is more than one age of mafic component. Widespread sheet-like bodies of amphibolite, 1 m thick on average, constitute more than 10% of the orthogneiss on a few outcrops. These sheets have sharp contacts and may be dykes. They are cut by the pegmatite veins but only locally cut by the granodiorite leucosome. Smaller mafic lenses and boudins are migmatitic and some are altered to a much more felsic composition, suggesting infusion of granodiorite melt. Near some of these inclusions, the granodiorite gneiss contains amphibole, suggesting contamination. Light grey-weathering orthogneiss, which forms 10 to 20 cm margins on some mafic sheets and occurs as local screens, may represent an early tonalite phase that has escaped migmatization or has reacted with the mafic rock.

Foliated granodiorite

The orthogneiss locally consists of more uniform, medium-grained, foliated granodiorite. Biotite-rich schlieren are widely dispersed or absent, but thick, weakly defined layering is present. The unit is cut only by a young pegmatite phase. The granodiorite is interpreted to have formed from thick injections or accumulations of granodiorite melt that are also represented by veining in the main phase of granodiorite gneiss.

Augen gneiss

A second subunit of the orthogneiss contains 6 cm long quartzofeldspathic lenses or augen in a slightly more mafic matrix of granodiorite gneiss. The rock extends along much of the north shore of Pearson Lake, north of a narrow belt of paragneiss (see below), where it grades into more typical granodiorite gneiss to the north. It contains an estimated average of 10% biotite and 5% hornblende. Similar to the main phase orthogneiss, it is cut by pegmatite veins and dykes. Augen, which constitute 80% of the rock, locally contain a large feldspar crystal (<15 mm long) in their core. The rock is similar to porphyroclastic granite and quartz monzonite west of the Thompson Nickel Belt (Zwanzig, 1999) but contains no fully preserved phenocrysts.

Paragneiss

A unit of intermediate to felsic paragneiss, heavily intruded by the various phases of the orthogneiss (see above), extends east-northeast along the northwest shore of Pearson Lake (Fig. GS-8-2). The intermediate rock contains quartz, feldspar, biotite and generally magnetite±garnet±hornblende. Migmatitic garnet-biotite gneiss, probably with graphite like the metagreywacke to the south of Pearson Lake, is also an important part of the paragneiss in the north. The intermediate compositions have an estimated average content of 15% biotite, 12% garnet, 12% hornblende and 1% magnetite, with the remainder being quartz and feldspar. The intermediate rock grades into magnetite-garnet amphibolite and more felsic garnet-biotite gneiss. The most mafic rock has the highest content of magnetite and is interpreted to be an Fe-rich sedimentary rock, although the local layering (<20 cm thick) cannot be clearly interpreted as bedding. The most felsic rock has about 50% granodiorite veins (<1.5 cm thick). Narrow inclusions and schlieren in the adjacent granodiorite gneiss contain hornblende-magnetite or garnet. The western part of the narrow paragneiss belt generally contains migmatitic garnet-biotite gneiss in the north and magnetite-biotite gneiss with rare garnet in the south. One exposure consists of well-preserved metagreywacke-derived migmatite with remnants of bedding.

Greywacke Migmatite

Much of the south shore of Pearson Lake is underlain by highly migmatitic garnet-biotite gneiss (diatexite) with

³ The terms 'Sickie Metamorphic Suite' and 'Burntwood River Metamorphic Suite' were used by Lenton and Corkery (1981) instead of the current terms 'Sickie Group' and 'Burntwood Group'.

porphyroblasts of cordierite and flattened quartz-sillimanite lenses (faserkiesel). South of the lake and in southern bays, layered (stromatic), greywacke-derived migmatite (metatexite) retains more primary characteristics (e.g., compositional grading), with increasing content of biotite interpreted to represent sedimentary grading from sandstone to mudstone, possibly from turbidite beds.

The greywacke metatexite typically weathers medium grey, with brown or red areas associated with traces of graphite±pyrrhotite, similar to metatexite units elsewhere in the Kiseynew Domain. The rock generally contains about 15% biotite and 10% garnet±sillimanite±cordierite. Leucosome occurs as early quartz- and feldspar-rich lenses (<10%) and leucogranodiorite to pegmatite veins (approx. 20%), 2 mm to 20 cm thick. Some veins contain partly chloritized porphyroblasts of cordierite or selvages with garnet, cordierite and small white lenses containing fibrolitic sillimanite. Thicker sills of granodiorite locally contain garnet±cordierite, suggesting contamination or partial melting of greywacke gneiss.

The greywacke diatexite weathers light grey and forms high outcrops. Granodiorite leucosome locally forms 80% of the rock, with only schlieren and local well-defined inclusions of metagreywacke. On the southeast shore of the lake, diatexite is rich in biotite and relatively homogeneous, with widespread quartz-rich lenses and feldspar, garnet and cordierite porphyroblasts (5–30 mm). It probably formed from Al-rich mudstone.

Structure

Gneissic foliation and major geological contacts are subparallel and straight to undulose in the vicinity of Pearson Lake, suggesting high strain throughout the area. The strike is east-northeast and the dip is subvertical (Fig. GS-80-2). All rock types are foliated except the latest pegmatite veins. The foliation in granodiorite gneiss is defined by mineral and augen alignment, concentrations of mafic minerals (mainly biotite) and parallel granodiorite veins. Mafic sheets and boudins are subparallel to the foliation and show progressively increased flattening with relative age. Stretching lineations plunge steeply west and crenulations plunge gently east. Layering in greywacke migmatite is interpreted as structurally transposed bedding with parallel veins and lenses of leucosome. Where several relative ages of leucosome occur together, a progressive increase in the development of the foliation suggests synkinematic migmatization. Local north-northeast-trending foliation may represent domains with a relatively early gneissosity.

A set of northwest-trending, steeply dipping dextral shear bands is prominent in granodiorite gneiss, particularly along the north shore of Pearson Lake, where the mean trend of the main foliation is east (Fig. GS-8-2). Accordingly, a significant component of dextral shear was part of the regional deformation. Many of the shear bands contain granodiorite leucosome or pegmatite formed during intermediate to late stages of the deformation. Minor folds are predominantly Z shaped, plunge steeply and have axial surfaces that strike northeast, a style that is consistent with dextral transpression during the development of the east-northeast-trending regional plane of deformation.

Sampling

Sampling was carried out after units had been identified and their relative ages and contact relations recorded. Where possible, each sample consists of a single rock type, intrusive phase or gneissic component with clearly defined contact relations. The collection includes samples of all units of paragneiss and all observed relative ages of orthogneiss and pegmatite.

Multiple samples were collected from all units and subunits for petrographic thin-section analysis and for modal analysis on slabs stained to distinguish quartz, K-feldspar and plagioclase. All major felsic units were also sampled for geochemistry, Sm-Nd isotope geochemistry and U-Pb zircon and/or monazite geochronology. The approximately 15 kg samples collected for these purposes comprise fresh broken pieces trimmed in the field on the sampled rock type, to remove weathered surfaces while avoiding possible contamination. About 1 kg was set aside for whole-rock and trace-element analysis.

MYSTERY LAKE-ODEI RIVER AREA

Re-examination of drill core from the MEL Zone property between Mystery Lake and the Odei River (Fig. GS-8-1) was carried out in the Inco Technical Services Limited yard in Thompson. Units were identified and described for future comparison with better known units in the TNB and the Kiseynew Domain. Core was cut and sampled for thin-section and Sm-Nd isotope analysis; two 10 to 15 kg samples were collected for U-Pb zircon dating.

BURNTWOOD RIVER-MYSTERY LAKE AREA

Low water conditions in the Burntwood River this summer provided a rare opportunity to study river shoreline outcrops, interpreted as part of the Ospwagan Group, and the intrusive contact of the Mystery Lake granodiorite (Thompson Nickel Belt Geology Working Group, 2001). A group of outcrops, mainly northeast of the Highway 391 bridge, were mapped in detail for comparison with part of the type section of the Ospwagan Group on the shoulder of the Pipe II open pit. Particular attention was given to the contact with granodiorite west of the Burntwood River. Samples were collected for petrographic description and chemical analysis of all units, and in an attempt to obtain a high-precision U-Pb zircon age of the granodiorite. The country

rock east of the granodiorite was further examined on the west shore of Mystery Lake. If successful, this work may provide an age of crystallization for the granodiorite, a point in time during the development of the high-strain fabric and a minimum age of sedimentation for the Ospwagan Group.

Preliminary Observations

The small detailed map area features eight lithological units interpreted to be from the P3 member of the Pipe Formation in the Ospwagan Group, as well as granodiorite of the Mystery Lake pluton. The main P3 marker unit is a layer of buff dolomitic marble that is in contact with, or surrounded by, iron-formation. The marble unit pinches and swells to a maximum thickness of 20 cm and is in direct contact with the granodiorite over much of the exposure. The iron-formation weathers brown or green, depending on its content of magnetite or diopside. It is interfingered with massive chert layers in the east and overlain by beige- and green-layered calc-silicate rock. The rocks of the Ospwagan Group are highly foliated to sheared; mylonite occurs several metres east of the contact with the granodiorite and as rafts in the granodiorite. However, despite the high strain, all of the layers closely resemble groups of beds in P3 and have been sampled to confirm this interpretation using petrography and geochemistry. Grey semipelite that lies east of the granodiorite on the west shore of Mystery Lake is tentatively interpreted as the P2 member of the Pipe Formation, suggesting that the granodiorite may cut across Ospwagan Group stratigraphy.

The Mystery Lake granodiorite weathers light grey to buff, is leucocratic (<5% biotite) and contains muscovite, which is typical of the main body of the intrusion. The following detailed field observations suggest that the sedimentary rocks are intruded by the granodiorite:

- Much of the margin is sheared or mylonitic, but moderately foliated granodiorite adjacent to the sedimentary rocks mapped in detail has a 10 cm band of dark material that may represent an original contaminated contact zone.
- The granodiorite is more pegmatitic near the contact with the sedimentary rocks than in areas closer to the centre of the pluton.
- Inclusions of the mylonitic metasedimentary rocks occur in the sheared granodiorite. Some of their terminations are angular, cut by the foliation and indicate that the inclusions are xenoliths.

The high strain is interpreted to predate and postdate the intrusion of granodiorite.

ACKNOWLEDGMENTS

We thank Inco Technical Services Limited and Nuinsco Resources Limited for access to their drill core and for the generous assistance of the Inco staff, particularly Larry Larson.

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by C.D. Lettley¹

Lettley, C.D. 2001: Hydration of Pikwitonei Domain granulite along the east margin of the Thompson Nickel Belt (part of NTS 63J/16); In Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 57-58.



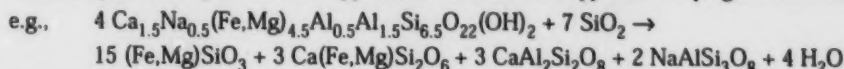
SUMMARY

A study along the east margin of the Thompson Nickel Belt (TNB) was undertaken in order to characterize the metamorphic transition from granulite of the Archean Pikwitonei Granulite Domain to amphibolite-grade gneiss of the Paleoproterozoic TNB. In the summer of 2000, samples of granulite and Paleoproterozoic mafic dykes (Molson swarm), and the equivalents of both these rock types retrogressed to varying degrees through Hudsonian overprinting, were gathered from western Sipiwes Lake and the Wabowden region (Lettley, 2000). These samples have since been characterized through thin-section petrography, whole-rock geochemical analysis and electron-microprobe analysis. The results have been presented in fulfillment of B.Sc. thesis requirements (Lettley, 2001). A visit to Sipiwes Lake in the summer of 2001 revealed that the water level in the lake has risen substantially in the past year, submerging most of the outcrop on which this study is based.

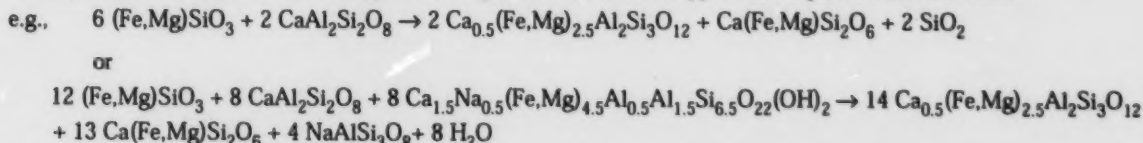
RESULTS

Based on mineral-phase stability, the conditions under which the granulite formed are approximated as 850°C and 900 MPa (9 kbar). The following reactions have been identified in the granulites:

- a) calcic amphibole + quartz → orthopyroxene + Ca-rich clinopyroxene + plagioclase + water



- b) orthopyroxene + anorthite ± calcic amphibole → garnet + Ca-rich clinopyroxene ± quartz ± albite ± water



Reaction (b) has only taken place in layers of mafic granulite that have a Mg# less than 0.55.

Ambient conditions at the time of Molson dyke emplacement (1883 Ga in Heaman et al., 1986), as identified through deuterium alteration assemblage, were approximately 600°C and 500 MPa (5 kbar).

A hydration front associated with pegmatite and quartz veins is locally readily apparent at the eastern margin of the TNB (Fig. GS-9-1). Amphibolite that is reworked within the TNB can be highly disrupted (Fig. GS-9-2) and mineral assemblages are altered or partly altered by hydration (Fig. GS-9-3). This Hudsonian alteration along the extreme east margin of the TNB

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Figure GS-9-1: Boundary between unaltered granulite (left) and statically hydrated material associated with pegmatite veins (right) in the easternmost granulite affected by static hydration associated with pegmatite and quartz veining during Hudsonian overprinting. Individual lithological layers can be traced across such boundaries. Contrast between altered and unaltered granulite was digitally enhanced. Soft-drink can for scale at top of photo.



took place under conditions of approximately 600 to 650°C and 500 MPa (5 kbar). The alteration consists of static, largely isochemical hydration along digitate zones associated with discordant pegmatite and quartz veins. The alteration led to the replacement of pyroxene, largely with calcic amphibole and cummingtonite. A deformational front and associated pervasive alteration occur less than 1.5 km to the west of the hydration front. In situ melting took place to the west of this front, with postdeformational pegmatite veins situated near the front.

Amphibolite units sampled from reworked basement material in the core of the TNB, near Wabowden, have compositions and rare-earth element distributions that are consistent with that of the granulite at Sipiwesik Lake. This suggests that the TNB amphibolite units were derived from the granulite or related gneiss.

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I would like to thank R.K. Springer and Josef Macek for the input and guidance they provided throughout this study.

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Figure GS-9-2: Amphibolite gneiss found to the west of the deformational front. Note the disrupted nature of the layering and the postdeformational aplite vein that cuts the gneiss. Metal box in background is 20° cm high.

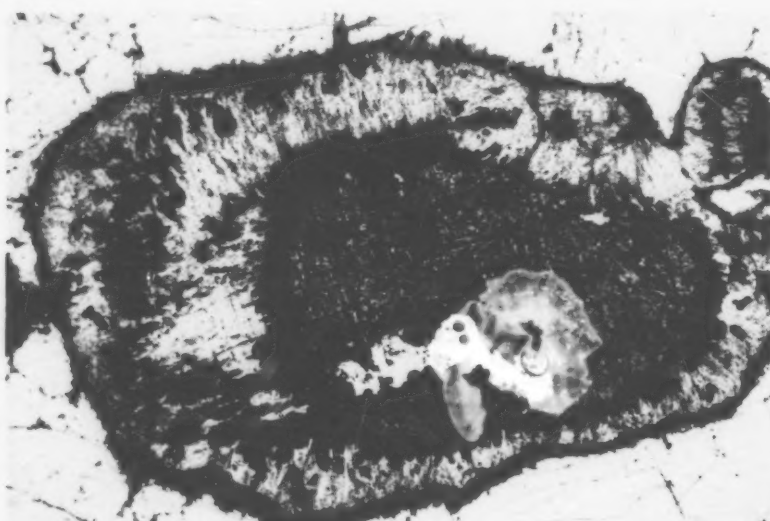


Figure GS-9-3: Incomplete alteration of an orthopyroxene grain from statically hydrated granulite. The dark outer rim is composed largely of biotite, and the inner, pale zone is composed largely of cummingtonite. The dark material within the cummingtonite zone and immediately rimming the orthopyroxene core is in optical continuity with the orthopyroxene. Field of view is 7 mm.

GS-10 PEGMATITE REMAGNETIZATION AT ABOUT 1.7 GA IN THE SOUTHERN THOMPSON NICKEL BELT, FROM PALEOMAGNETISM

by M.J. Harris¹, D.T.A. Symons¹, D.C. Peck², W.H. Blackburn³ and A. Turek¹

Harris, M.J., Symons, D.T.A., Peck, D.C., Blackburn, W.H. and Turek, A. 2001: Pegmatite remagnetization at about 1.7 Ga in the southern Thompson Nickel Belt, from paleomagnetism; in Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 59-66.

SUMMARY

A paleomagnetic study on ca. 1770 Ma pegmatites and associated host rocks in the Thompson Nickel Belt now extends the apparent polar wander path for ancestral North America from 1.8 Ga to 1.7 Ga. Standard paleomagnetic techniques and tests show that the host gneissic units next to the pegmatites have been remagnetized either during or after pegmatite emplacement and, therefore, the host rocks carry the same magnetic remanence as the pegmatites. The shared paleopole is located at 30.7°N, 92.2°W ($dp = 10^\circ$, $dm = 11^\circ$) in present-day Louisiana. Extrapolation of the polar wander path from the 1776 Ma Deschambault pegmatites pole in the Glennie Domain suggests that magnetization of the Nickel Belt pegmatites and their host gneissic units occurred around 1740 to 1720 Ma.

INTRODUCTION

Twenty-four paleomagnetic studies, funded by LITHOPROBE, have been carried out in the University of Windsor Paleomagnetism Laboratory on rocks from the Trans-Hudson Orogen (THO) and Superior Boundary Zone (SBZ; Fig. GS-10-1). The results document continental accretion from ca. 1880 Ma to 1776 Ma, through the assembly of the Flin Flon Belt, Hanson Lake Block, Lynn Lake-La Ronge Domain and Superior craton with the Hearne craton (Fig. GS-10-2; Symons, 1998; Symons and MacKay, 1999; Symons and Harris, 2000). During the assembly, some 5500 km of Manikewan oceanic crust was

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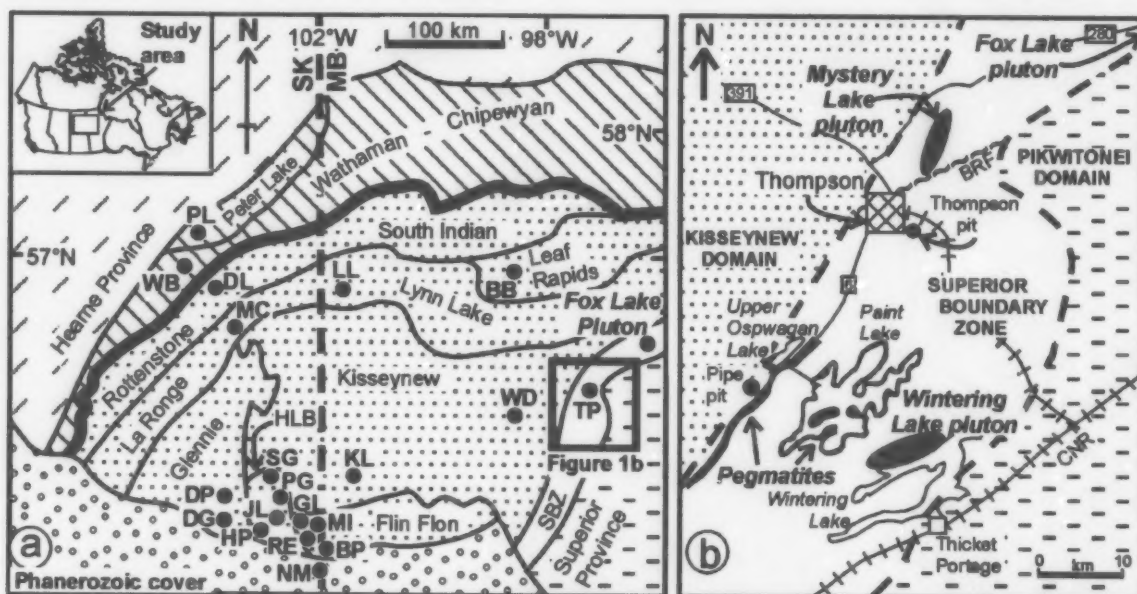


Figure GS-10-1: a) Tectonic elements of the Trans-Hudson Orogen and location of the Fox Lake pluton (after Harris et al., 1999b, 1999c, 2000). Abbreviations: SBZ, Superior Boundary Zone; HLB, Hanson Lake Block; MB, Manitoba; SK, Saskatchewan. Dots show paleomagnetic collection locations: BB, Baldock Batholith (Symons et al., 1996b); BP, Boot Lake-Phantom Lake Complex (Symons and MacKay, 1999); DG, Deschambault Lake granite (Symons et al., 1996a); DP, Deschambault Lake pegmatites (Symons et al., 2000); GL, Granite Lake pluton (abandoned); HP, Hanson Lake pluton (Gala et al., 1994); JL, Jan Lake granite (Gala et al., 1995); KL, Kississing Lake dome (Symons and Harris, 1998); LL, Lynn Lake gabbro (Dunsmore and Symons, 1990; Turek et al., 2000); MC, Macoun Lake granite (Symons et al., 1994); MI, Missi conglomerate (Symons and Lewchuk, 1994); NM, Namew Lake gabbro (abandoned); PG, Pelican granulite (abandoned); PL, Peter Lake gabbro (Symons, 1994); RE, Reynard Lake granodiorite (Symons, 1995); SG, Sahli granulite (Gala et al., 1998); TP, Thompson pegmatites (this study); WB, Wathaman Batholith (Symons, 1991); WD, Wapisi Lake dome (Symons and Harris, 2000). b) Locations of collections near Thompson, Manitoba. Abbreviations: BRF, Burntwood River Fault; CNR, Canadian National Railway.

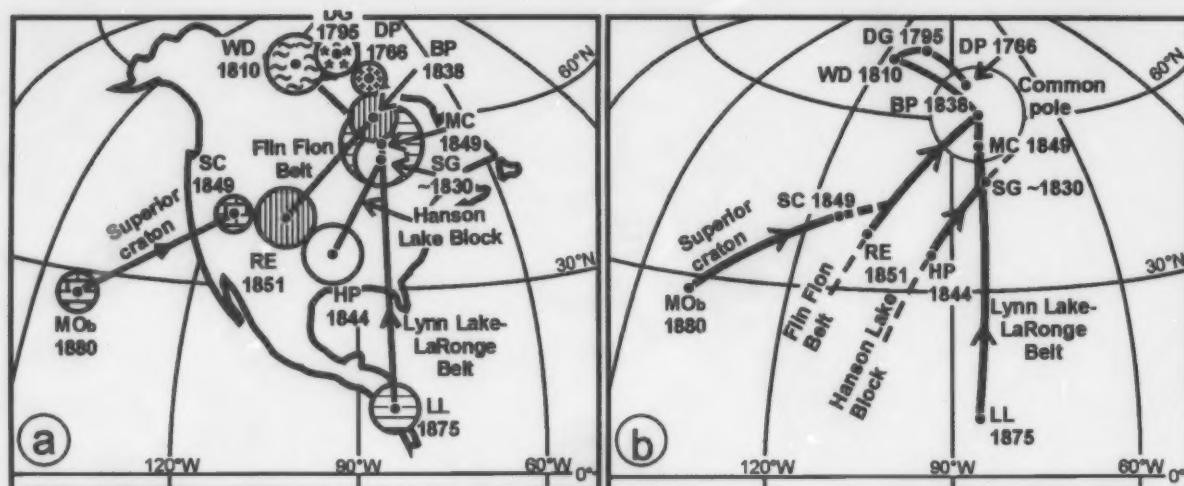


Figure GS-10-2: a) Apparent polar wander path (APWP) segments for the Superior craton and the Trans-Hudson Orogen domains from ca. 1875 to ca. 1766 Ma. Abbreviations for poles as indicated in Figure GS-10-1, with their magnetization ages in Ma; MOb, Molson dikes b-pole (Halls and Heaman, 2000); SC, Sudbury Complex (Morris, 1984). b) Projection of the APWP segments to the ca. 1840 to ca. 1810 stillstand and hairpin (Symons and Harris, 2000).

destroyed (Dunsmore and Symons, 1990). Following accretion, two 'hairpins' in the apparent polar wander path (APWP) occurred at ca. 1830 and ca. 1810 Ma (Fig. GS-10-2; Symons, 1998; Symons and Harris, 2000; Symons et al., 2000).

Prior to these studies, the Superior craton was only represented by poles from two studies (Fig. GS-10-2), specifically the 1880 Ma Molson dykes (Zhai et al., 1994) and the 1849 Ma Sudbury Complex (Morris, 1984). Paleomagnetic studies on three plutons in the SBZ with ages between 1836 and 1818 Ma have since been reported (Fig. GS-10-1; Harris et al., 1999b, 1999c, 2000; Harris et al., work in progress, 2001). This is the fourth paleomagnetic study in the SBZ, and reports results from ca. 1770 Ma pegmatites and associated host rocks within their 'baked zones' (i.e., the rocks next to the pegmatites that are thought to have been heated and remagnetized during pegmatite emplacement).

GEOLOGY

The tectonically late pegmatites have intruded supracrustal rocks of the Thompson Nickel Belt. The belt derives its name from its many Ni-sulphide deposits, including the world-class deposit of the Thompson mine. Most of the nickel deposits are hosted by paragneiss of the Ospwagan Group. However, many of the rocks in the belt are polymetamorphosed migmatitic orthogneiss that probably represents reworked Pikwitonei-type granulite observed in adjacent parts of the SBZ (Weber, 1990). Characteristic metamorphic conditions for the sampled area of the Thompson Nickel Belt are temperatures of 600 to 660°C and pressures between 500 and 600 MPa (Bleeker, 1990).

Specifically, the sampled host rocks include mafic orthopyroxene granulite, metatonalitic to enderbitic gneiss, migmatite, pillowed metabasalt, quartzofeldspathic gneiss and amphibolitic gneiss, all derived from Archean protoliths (Stephanson, 1974; Hubregtse, 1978; Bleeker and Macek, 1988). Amphibolite or diabase assigned to the ca. 1880 Ma Molson dyke swarm were also present in the area and collected (e.g. Table GS-10-1, samples PP07 and UOL05).

All pegmatites observed and sampled are simple in their mineralogy and texture. They are massive, medium to coarse grained and leucocratic, having less than 5% biotite as their mafic mineral content and otherwise having a granitic composition. They range in colour from white through pink to pinkish orange, generally reflecting their alkali feldspar content, but also display some minor iron-oxide alteration.

PALEOMAGNETIC METHODS

Sixteen sites were originally collected in 1994, specifically sampling the ca. 1770 Ma pegmatites from the Thompson pit (eight) and the Pipe pit (eight) of Inco Ltd. The pegmatites did not provide coherent paleomagnetic results, but several contact tests, which sampled the host rocks in the baked zone of the pegmatites, provided useful information. Therefore, a second round of 16 new sites was collected in 1998, emphasizing the baked zones of the pegmatites (Table GS-10-1). The new sites (Fig. GS-10-3) were collected at the west end of Upper Ospwagan Lake (five), on Paint Lake (seven) and along Highway 6 (four). Except for one granitic gneiss site on Paint Lake, all other new sites were collected as contact tests between pegmatite and hosting gneiss. Six of the eight sites in the Pipe pit sampled pegmatite, one site sampled the host gneiss and the eighth site sampled a mafic dyke correlated to the Molson dyke swarm. The original eight sites sampled in the Thompson pit yielded incoherent results and are therefore not discussed further.

Table GS-10-1: Accepted ($\alpha_{95} < 20^\circ$) site-averaged paleomagnetic data for the Pipe pit area.

Site PP	N, n	Dec. (°)	Inc. (°)	α_{95} (°)	k
01Pg	14, 8	103.2	77.7	18.6	10
02Gn	21, 10	49.8	71.5	15.0	11
06Pg	7, 3	75.2	55.9	20.6	37
07Mda	35, 13	276.6	33.5	14.0	10
07Mdb	35, 10	73.7	24.8	12.9	15
Hwy 6					
01Gn	7, 4	89.1	74.4	18.1	27
02Gna	10, 5	359.7	54.2	20.6	15
03Gnb	10, 5	244.2	42.5	18.0	19
UOL					
05Md	9, 8	177.2	37.9	7.0	20
06Gn	8, 7	171.0	66.6	7.5	65
07Gn	7, 7	170.8	65.8	3.3	328
07Pg	7, 7	245.1	83.5	11.7	28
08Pg	8, 6	225.0	70.0	10.4	43
09Mb	13, 11	181.5	81.1	10.5	20
PL					
10Gn	15, 15	152.5	72.6	7.5	27
10Pg	4, 4	161.8	60.6	17.8	27
11Am	7, 7	191.9	62.2	7.0	75
11Pg	6, 5	159.6	73.0	16.0	24
12Gn	9, 9	224.7	27.1	5.6	85
12Pg	6, 5	175.2	78.6	11.8	43
13Gn	10, 10	195.5	67.9	6.8	52
14Gn	7, 6	149.7	76.7	13.4	26
14Pg	6, 5	294.5	84.0	12.3	39
15Gn	10, 10	162.8	77.9	12.6	16
15Pg	6, 4	153.6	66.6	18.4	26
16Am	16, 13	186.6	60.8	9.1	12

Abbreviations: N, total number of specimens; n, number of specimens used in the average; Dec., declination; Inc., inclination; α_{95} , radius of cone of 95% confidence; k, precision parameter; PP, Pipe pit; Hwy 6, Highway 6; UOL, Upper Oswagan Lake; PL, Paint Lake; Am, amphibolite; Gn, granitic gneiss; Mb, metabasalt; Md, mafic dyke; Pg, pegmatite.

At each site, five to fifteen (average of seven) 2.54 cm diameter cores were drilled and oriented in situ, in most instances with a sun compass but periodically checked with a magnetic compass. More than 275 specimens, each with a length of 2.2 cm, were sliced from the cores to represent this collection (Table GS-10-1).

All paleomagnetic measurements were done at the University of Windsor Paleomagnetism Laboratory using an automated CTF DRM-420 cryogenic magnetometer, a Sapphire Instruments SI-2b susceptibility meter, a Sapphire Instruments SI-4 alternating field demagnetizer, a Sapphire Instruments SI-5 spinner magnetometer, a Sapphire Instruments SI-6 pulse magnetizer, and a Magnetic Measurements MMTD-1 or MMTD-80 thermal demagnetizer. These instruments are housed in a triple-layer magnetically shielded room that has an ambient magnetic field of approximately 0.2% of the Earth's magnetic-field intensity.

After storage for several months within the shielded room, each specimen's natural remanence magnetization (NRM) was measured. The magnetization intensity of the pegmatites ranged from 4.2×10^{-5} to 3.5×10^0 amperes per metre (A/m), with a median intensity of 7.4×10^{-4} A/m, first quartile (Q_1) of 2.4×10^{-4} A/m and third quartile (Q_3) of 2.5×10^{-3} A/m. The gneissic units had an intensity range of 4.0×10^{-5} to 2.0×10^0 A/m, a median intensity of 5.4×10^{-3} A/m, Q_1 of 1.5×10^{-3} A/m and Q_3 of 1.5×10^{-2} A/m.

Two pilot specimens were selected from each rock type at each site. The specimens chosen had an 'average' NRM direction and intensity for the rock type at the site. One pilot specimen was demagnetized in an alternating field (AF) in 11 steps from 5 to 130 millitesla (mT), and the other was thermally demagnetized in 12 steps from 200 to 570°C.

In general, the thermal demagnetization intensity curves suggested the presence of fine-grained magnetite with substantial remanence decay between 520 and 570°C (Fig. GS-10-4, curve a). Titanomagnetite or coarse-grained magnetite was also suggested by the gradual intensity decay over the entire temperature range of 200 to 570°C (Fig. GS-10-4, curve b). Some specimens retained up to 90% of their NRM intensity at 570°C, suggesting that they contain hematite (Fig. GS-10-4, curve c). A few specimens showed dramatic intensity drops in the 260 to 320°C range, suggesting the presence of pyrrhotite (Fig. GS-10-4, curve d).

Evaluation of the thermal decay curves and the orthogonal step demagnetization plots (Fig. GS-10-5; Zijdeveld, 1967)

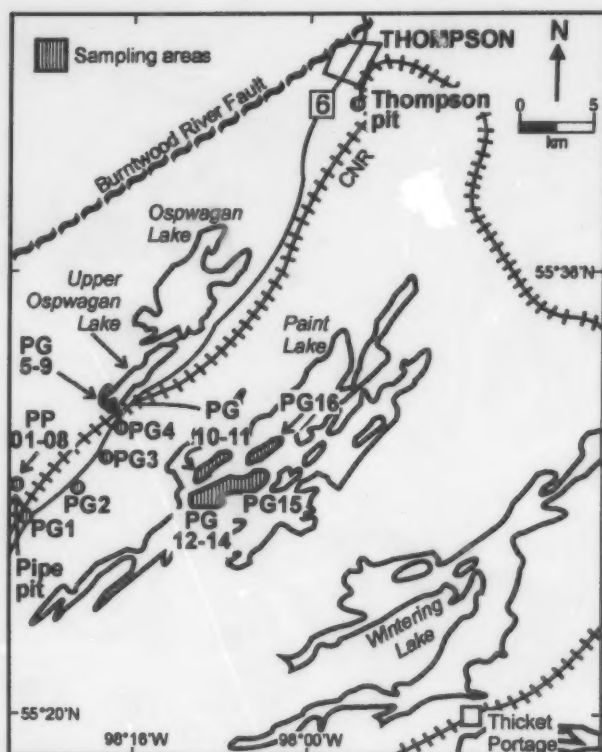


Figure GS-10-3: Sampling locations for the gneissic units and pegmatites in the Pipe pit and Paint Lake area. Samples with the PP prefix were collected in 1994; samples with the PG prefix were collected in 1998.

Figure GS-10-4: Thermal decay curves for representative specimens of the gneissic units and pegmatites. Typical unblocking temperature ranges for pyrrhotite and magnetite (P and M, respectively) are shown along the bottom. The vertical axis, J/J_{NRM} is the ratio of the measured intensity to the NRM intensity.

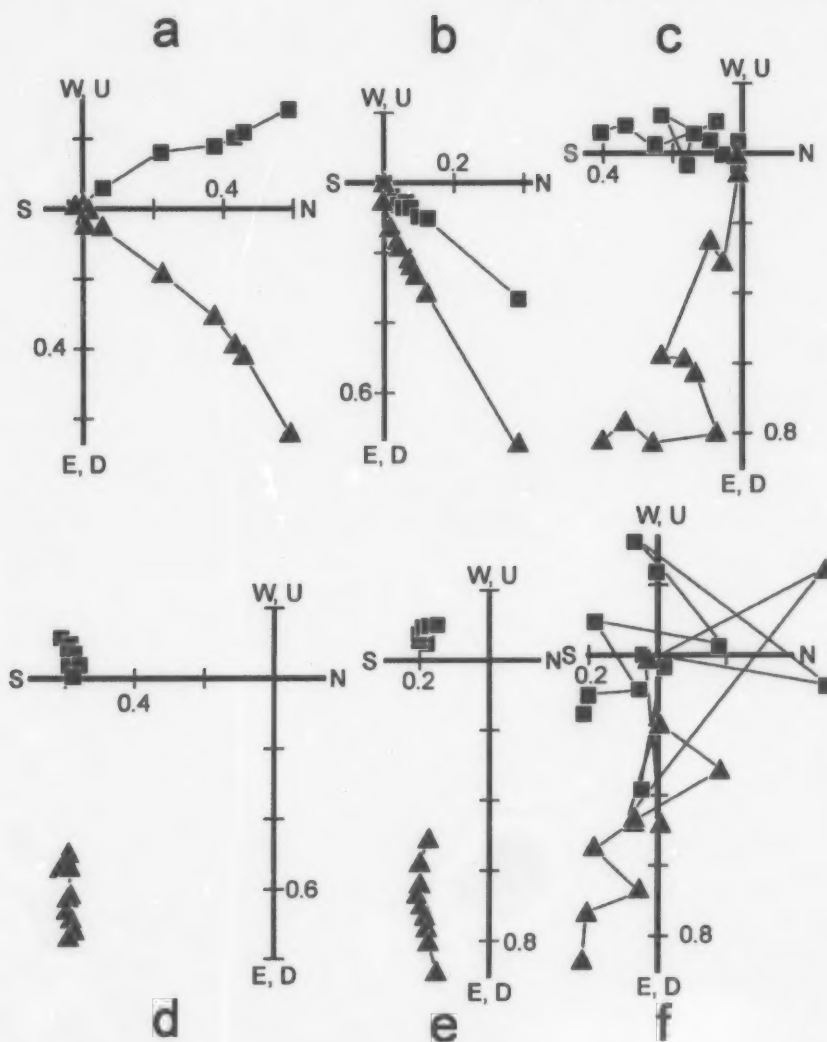
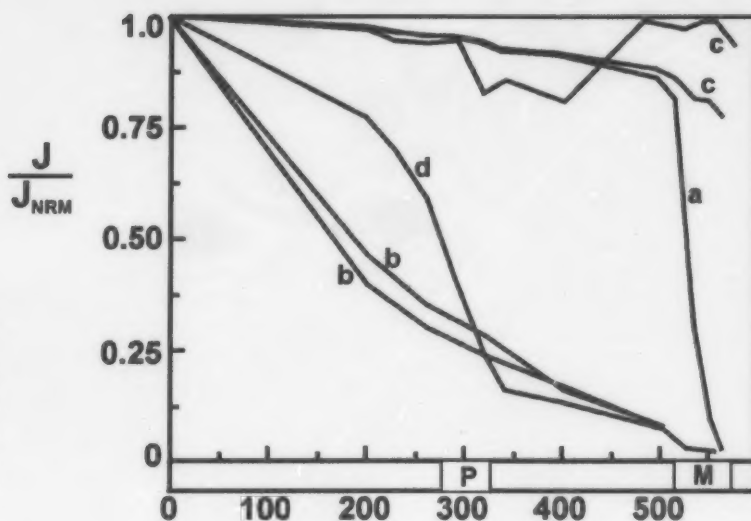


Figure GS-10-5: Representative orthogonal-step demagnetization plots (Zijderveld, 1967) for selected specimens from the Pipe pit area. Squares are projected in the horizontal plane (West-North-East-South) and triangles are projected in the vertical plane (Up-North-Down-South). Specimens are from a) site 2, gneiss; b) site 14, gneiss; c) site 10, gneiss; d) site 5, mafic dyke; e) site 11, pegmatite; f) site 3, pegmatite.

suggested that half of the remaining specimens should be AF demagnetized and the other half thermally demagnetized, using a schedule similar to those used for the pilot specimens.

Specimen characteristic remanent magnetization (ChRM) directions were calculated using the standard end-point method of Kirschvink (1980). Specimen ChRM directions were accepted for statistical analysis if their best-fit stable direction had a maximum deviation of less than 20° over three or more consecutive steps, with most having deviations of less than 10°. Site and unit mean directions were calculated using the statistical methods of Fisher (1953).

Results

The majority of specimens from Paint Lake possessed a single ChRM direction that decayed linearly to the origin on orthogonal-step demagnetization plots (Fig. GS-10-5a, b). Some specimens carried a weak remanence in the present Earth's magnetic-field direction that was removed by the initial demagnetization steps (Fig. GS-10-5c). Some specimens with minor hematite components were not completely demagnetized by either AF or thermal demagnetization techniques (Fig. GS-10-5d, e). Most specimens from the Pipe pit and those collected along Highway 6 either did not yield coherent ChRM directions or were too weakly magnetized to produce useful data (Fig. GS-10-5f).

Acceptable site mean directions with a radius for their cones of 95% confidence (α_{95}) of less than 20° were calculated for 19 of the 36 sites (Table GS-10-1). Most of these sites yielded mean directions with normal-polarity steeply down inclinations (Fig. GS-10-6). Four sites yielded anomalous inclinations of less than 45° and somewhat less than 10% of all specimens yielded reversed-polarity directions with random inclinations.

All samples were collected within approximately 100 km², a geologically small area. However, because they were collected from different rock types, their mean directions were compared statistically to test the possibility that they carry a common magnetic direction.

The 13 sites of granitic gneiss yielded a mean ChRM direction of declination (Dec.) = 199.2°, inclination (Inc.) = 75.6°, α_{95} = 14.8° and precision parameter (k) = 9. The nine pegmatite sites yielded a mean ChRM direction of Dec. = 152.3°, Inc. = 79.1°, α_{95} = 11.6° and k = 21. The two amphibolite sites and the metabasalt site were combined and yielded a mean ChRM direction of Dec. = 188.1°, Inc. = 68.0°, α_{95} = 17.6° and k = 50. The mafic dyke directions at site 07 in the Pipe pit and at site 05 on Upper Oswegan Lake have shallow down inclinations but are discordant with the other rock type directions and each other (Table GS-10-1; Fig. GS-10-6), and are therefore not discussed further.

The ChRM directions for the granitic gneiss sites and the pegmatite sites were compared statistically using the F-test of McFadden and Lowes (1981) to see if they could come from one population, or if they were two separate populations. The F-test was positive because the calculated value was much less than the tabulated statistic (i.e., $F_{\text{calc}} = 0.934 < F_{\text{tab}} = 3.49$, $N = 22$). Therefore, these 22 sites carry a similar magnetic direction, and they show that the magnetizing event is no older than the emplacement age of the pegmatites. The location of the paleopole for the gneiss and the pegmatites is located at 30.7°N, 92.2°W ($dp = 10^\circ$, $dm = 11^\circ$), in present-day Louisiana (Fig. GS-10-7).

DISCUSSION

Several ages have been determined for the pegmatites in the study area. A pegmatite associated with the Wintering Lake pluton yielded a K-Ar biotite age of 1812 Ma (Moore et al., 1960). Another pegmatite from Paint Lake, on the same island as our site 16 (Fig. GS-10-3; Table GS-10-1), yielded a U-Pb zircon age of 1786 $\pm 3/-2$ (Krogh et al., 1985). A third pegmatite from the Pipe pit yielded a Pb-Pb zircon age of 1768 (Machado et al., 1987). Further, there is general consensus that abundant pegmatite emplacement occurred across the whole of the Trans-Hudson Orogen and Superior craton between 1780 and 1770 (Weber, 1990; Machado, 1990).

There is, however, a concern that the pegmatites in the Pipe pit area do not carry a ca. 1770 Ma magnetization because the pole position differs from that of the 1776 Ma Deschambault pegmatites in the Glennie Domain (Fig. GS-10-1, GS-10-7; Symons et al., 2000). With the assumption that THO accretion had ended by 1.8 Ga (Lewry and Collerson, 1990), all younger pegmatites should carry a similar paleopole. Therefore, it is suggested that the pegmatites in the Pipe pit area carry a magnetization that is younger than ca. 1770 Ma.

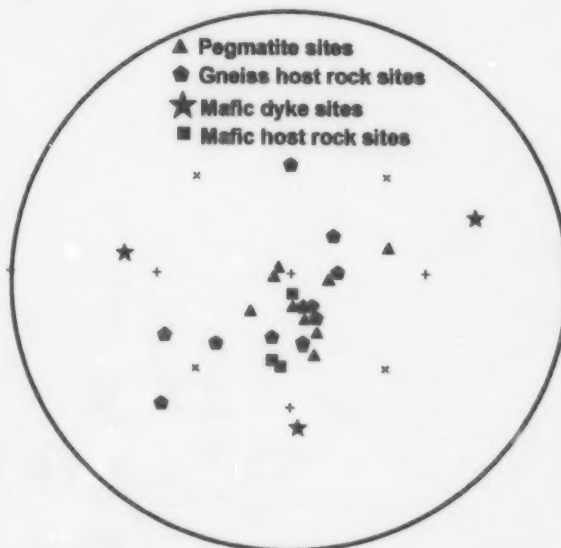


Figure GS-10-6: Equal-area stereograms showing the site mean directions for the sites in the Pipe pit area. Stars are mafic dykes, pentagons are gneiss, triangles are pegmatite and squares are amphibolite.

Other pieces of data also point to a magnetization age that is younger than 1770 Ma. Approximately 15 km south of Paint Lake, the Sasagiu Rapids granite has yielded a U-Pb zircon age of 1726 ± 12 Ma, interpreted as the age of intrusion (Machado et al., 1990). There are several ages between 1730 and 1720 Ma that are interpreted to be metamorphic or reset ages of various gneissic units in the area (Lowdon, 1961; Lowdon et al., 1963; Machado et al., 1990). Furthermore, the a-pole of the Molson swarm dykes is situated at 16.1°N , 96.5°W (Fig. GS-10-7), and has been interpreted to be a reset magnetization age in the range of 1.8 to 1.7 Ga (Halls and Heaman, 2000). The data, therefore, imply that the pegmatites were emplaced between 1812 and 1770 Ma, but that they and the amphibolite and gneiss were subsequently remagnetized at ca. 1720 Ma. The discordance between the Pipe pit area paleopole and the a-pole of the Molson swarm suggests that the former rocks likely cooled through their relevant magnetization temperatures some 40 to 20 Ma before the Molson swarm, as scaled off the APWP, assuming constant tectonic motion (Fig. GS-10-7).

Further, stressing the difference between the late 1.7 Ga poles, Halls and Heaman (2000) suggested that tectonic movements during the 2200 to 2100 Ma age frame were of 1° of arc per Ma or approximately 10 cm/a, a relatively rapid rate compared to Mesozoic and Tertiary motions (cf. Harris et al., 1999a). Scaling off the APWP (Fig. GS-10-7), and using 1° of arc per Ma, the Pipe pit area pole can be as old as ca. 1747 Ma and the a-pole for the Molson swarm would be ca. 1725 Ma. These ages correspond to magnetic resetting of the Pipe pit area rocks through metamorphism (Machado et al., 1990) and the Molson swarm pole would correspond with intrusion of the 1726 Ma Sasagiu Rapids granite (Machado et al., 1990). If slightly slower motion values are used, such as 7 cm/a, ages for the two poles would be 1729 and 1693 Ma, suggesting that the Pipe pit area rocks were remagnetized at the time of intrusion of the Sasagiu Rapids granite (Machado et al., 1990) and the Molson swarm was affected by uplift and reset ages reported between 1704 and 1690 Ma (Lowdon, 1961; Wanless et al., 1966, 1974). Although precise ages cannot be resolved at this time, a clearer picture of the Superior craton's APWP for the Early Proterozoic is emerging.

CONCLUSIONS

Pegmatite, gneiss and amphibolite in the Pipe pit area of the Thompson Nickel Belt, in the Superior Boundary Zone, appear to carry a remagnetization that yields a paleopole acquired between 1740 and 1720 Ma. The pole lies in present-day Louisiana at 30.7°N , 92.2°W ($dp = 10^\circ$, $dm = 11^\circ$) and permits interpolation of the APWP for the Superior craton and Trans-Hudson Orogen from the 1776 Ma pole for the Deschambault pegmatites through to the 1720 to 1700 Ma a-pole for the Molson dyke swarm.

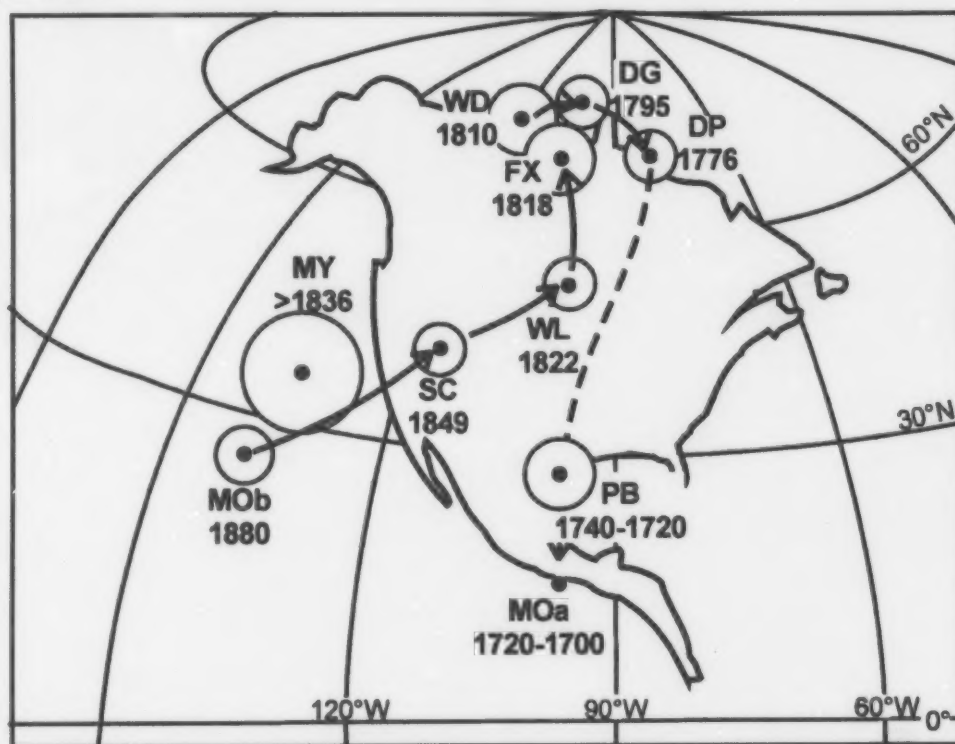


Figure GS-10-7: Paleopoles for collections from the Superior craton before accretion at ca. 1810 Ma and other Superior-THO paleopoles following 1810 Ma. Abbreviations as in Figure GS-10-1 and GS-10-2. MY, Mystery Lake pole (Harris et al., 1999b); WL, Wintaring Lake pole (Harris et al., work in progress, 2001), FX, Fox Lake pole (Harris et al., 2000), MOa, Molson swarm a-pole (Halls and Heaman, 2000); PB, Pipe pit area pole (this study).

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**GS-11 STRUCTURAL ANALYSIS AND INVESTIGATIONS OF SHEAR-HOSTED GOLD
MINERALIZATION IN THE SOUTHERN LYNN LAKE GREENSTONE BELT (PARTS OF
NTS 64C/11, /12, /15, /16)**

by C.J. Beaumont-Smith, S.D. Anderson and Ch.O. Böhm¹

Beaumont-Smith, C.J., Anderson, S.D. and Böhm, Ch.O. 2001: Structural analysis and investigations of shear-hosted gold mineralization in the southern Lynn Lake greenstone belt (parts of NTS 64C/11, /12, /15, /16); in Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 67-75.



SUMMARY

Continuing structural analysis of the southern Lynn Lake greenstone belt has delineated six generations of ductile to brittle-ductile fabrics. Overprinting relationships among the various generations of fabric suggest that the deformations represent discrete deformation having different kinematic frames. The oldest deformation (D_1) is responsible for the tectonic assembly of Wasekwan Group metavolcanic rocks prior to the intrusion of abundant plutons and the deposition of Sickle Group fluvial-alluvial arenaceous rocks. An intense D_2 transposition-shearing deformation overprints the D_1 geometry, producing the east-west distribution of the greenstone belt. Transposition associated with D_2 is characterized by the development of shallowly plunging, upright, F_2 isoclinal folds. The geometry of F_2 folds suggests a shallow pre- D_2 surface, a geometry most easily explained by D_1 thrust imbrication of the Wasekwan Group. Late-stage D_2 deformation is characterized by the development of regional-scale, D_2 dextral-transpressional shear zones. This is reflected in the development of D_2 shear zones within the greenstone belt, in addition to the previously identified Johnson Shear Zone developed along the southern margin of the belt. The overprinting of the resultant D_1/D_2 geometry by younger deformations does not result in the macroscopic reorientation of the pre-existing geometry.

Gold mineralization in the Lynn Lake greenstone belt is hosted by mafic and felsic metavolcanic rocks affected by D_2 shear zones. The delineation of D_2 shear zones within the greenstone belt significantly increases the amount of underexplored gold-prospective stratigraphy in the Lynn Lake belt beyond the Johnson Shear Zone. Known gold mineralization is accompanied by intense synshear alteration. The alteration assemblages have unique characteristics, controlled by the respective host rocks. Alteration associated with synshear gold mineralization hosted by mafic metavolcanic rocks is characterized by intense silicification, biotitization and carbonatization, and the introduction of finely disseminated pyrite. Synshear gold mineralization hosted by felsic metavolcanic rocks is accompanied by intense silicification, sericitization and the introduction of finely disseminated arsenopyrite. The economic potential of the newly delineated D_2 shear zones is highlighted by the identification of several alteration zones with intensities and assemblages similar to those associated with known gold mineralization.

INTRODUCTION

Structural analysis of the southern Lynn Lake greenstone belt and the companion investigation into shear-hosted gold mineralization represent two components of a regional study into the tectonic and metallogenic history of the north flank of the Kiseeynew margin. The geoscientific research in the Lynn Lake-Leaf Rapids area presented in this volume represents collaboration between the Manitoba Geological Survey (MGS) and the Geological Survey of Canada (GSC), in the form of a Targeted Geoscience Initiative (TGI). The goal of the TGI process is to foster research that provides an improved understanding of the mineral potential of the targeted region. Structural analysis and geochronological studies of the Lynn Lake greenstone belt are directed toward a better understanding of the deformational history of the belt and the metallogeny of shear-hosted gold mineralization in the belt.

Fieldwork undertaken in 2001 represents an expansion of the focus of structural analysis beyond the Johnson Shear Zone (JSZ; Beaumont-Smith and Rogge, 1999; Beaumont-Smith, 2000) to include significant portions of the Lynn Lake greenstone belt. The change in mandate reflects the requirement for a more regional understanding of the deformational history of the greenstone belt, in light of the complex tectonic assembly of the greenstone belt inferred from revised regional geochemistry (Zwanig et al., 1999) and the identification of multiple high-strain zones within the greenstone belt (Beaumont-Smith, 2000; Ma et al., 2000). This revised approach not only provides context for the shear zone-focused, mineral-deposits research, but also supports the ongoing geochemical work and newly initiated geochronological research. It is hoped that, by adopting a broader focus to the research, including regional geochronology, more direct comparisons with other juvenile arc and back-arc domains can be made, in order to aid the mineral-exploration community and provide a better understanding of the tectonic evolution of the Lynn Lake belt.

GEOLOGICAL SETTING

The Paleoproterozoic Lynn Lake greenstone belt (Fig. GS-11-1) comprises a diverse tectonostratigraphy in the form of two east-trending supracrustal belts of metavolcanic rocks and subordinate metasedimentary rocks, collectively assigned to the Wasekwan Group (Bateman, 1945). The age of the Wasekwan Group is approximately 1910 Ma (Baldwin et al., 1987).

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Figure GS-11-1: Geology of the Lynn Lake greenstone belt, highlighting the location of regional D_2 shear zones and alteration zones discussed in the text.

Both belts are characterized by mafic metavolcanic rocks that represent a wide variety of tectonic affinities, suggesting that the assembly of the greenstone belt involved significant tectonic juxtaposition early in its deformational history (see Zwanzig et al., 1999). The northern belt is dominated by a variety of submarine, tholeiitic, mafic metavolcanic and metavolcaniclastic rocks that are interpreted to represent an overall north-facing, upright, homoclinal succession. Included in the northern belt is the Agassiz Metaltect (Fedikow and Gale, 1982), a unique tectonostratigraphic succession consisting of ultramafic flows (picrite), banded oxide-facies iron-formation, and associated exhalative sedimentary rocks. The Agassiz Metaltect represents a relatively narrow stratigraphic-structural unit that has generally persistent strike-continuity along a significant portion of the northern belt (see Ma et al., 2000; Ma and Beaumont-Smith, GS-13, this volume). The southern belt is composed of submarine metavolcanic and metavolcaniclastic rocks, with tectonic affinities ranging from tholeiitic to calc-alkaline, and minor amounts of mid-oceanic ridge basalt (MORB) and ocean island basalt (OIB) that contribute to a complex tectonostratigraphy (Zwanzig et al., 1999).

The complex Wasekwan Group tectonostratigraphy was tectonically assembled prior to the intrusion of a variety of plutonic rocks, collectively assigned to the Pool Lake plutonic suite (Manitoba Energy and Mines, 1986). The plutons consist of weakly to moderately foliated gabbro to granite and have a three-fold age distribution: 1876 Ma (Baldwin et al., 1987) to 1871 Ma (Turek et al., 2000); 1857 to 1853 Ma (Machado, unpublished data); and 1832 Ma (Turek et al., 2000). These recently determined ages are consistent with the subdivision of intrusive rocks into early, middle and late successor-arc plutons, as applied in the Flin Flon Belt (Whalen et al., 1999), and suggest a similar complex magmatic evolution in the Lynn Lake belt.

Unconformably overlying the Wasekwan Group and 1876 to 1853 Ma plutons along the southern margin of the greenstone belt are coarse fluvial-alluvial arenaceous rocks of the Sickle Group (Norman, 1933; Gilbert et al., 1980). The basal Sickle conglomerate contains rounded supracrustal, plutonic and white vein-quartz cobbles, in a fine-grained arkosic to locally pelitic matrix. The conglomerate fines upward into thick-bedded, trough cross-bedded and cross-laminated arkose. The age of the Sickle Group is uncertain, but a preliminary detrital zircon age spectrum (Machado, pers. comm., 2000) and a composition and stratigraphic position similar to that of the 1850 to 1840 Ma McLennan Group in the La Ronge area of Saskatchewan (Ansdell et al., 1999) suggest a similar age for the Sickle Group.

A different clastic sequence, along the northern margin of the belt, consists of the Ralph Lake conglomerate and the Zed Lake greywacke. The sequence has an unknown age and is intruded by undated plutons. In this sequence, conglomerate composed of dominantly plutonic cobbles and minor supracrustal cobbles in an arenaceous matrix is overlain by pelite-poor turbidite. One similarity with the Sickle Group is the high concentration of magnetite within the lowermost conglomerate units.

Regional deformation, reflected in penetrative tectonic foliations, has affected all rocks in the Lynn Lake greenstone belt. The intensity of foliation development is highly variable throughout the belt and there is mesoscopic evidence of at least six phases of ductile and brittle-ductile deformation. The most intense phases of deformation have been overprinted by at least two metamorphic events, resulting in mineral assemblages that increase from upper greenschist facies in the Hughes Lake-Cockerm Lake area to upper amphibolite facies throughout other portions of the belt. The peak of metamorphism post-dates the assembly of the greenstone belt and the major transposition-shear zone development event (Beaumont-Smith and Rogge, 1999; Beaumont-Smith, 2000). Accordingly, metamorphic recrystallization has significantly modified many of the fabric elements developed during the major deformations.

STRUCTURAL ANALYSIS

Structural analysis of the Lynn Lake greenstone belt has identified six regionally penetrative, ductile deformation events (D_1 - D_6). These are based on differences in their kinematic framework and overprinting relationships. The oldest deformation (D_1) is largely inferred from a stratigraphic architecture in which different tectonic assemblages were juxtaposed to create a complex tectonostratigraphy within the Wasekwan 'Group'. In addition, reversals in pillow tops outline large-scale, east-northeast-trending F_1 folds, such as the McVeigh Lake anticline (Gilbert et al., 1980). These structures are cut by ca. 1876 Ma plutons. Mesoscopic D_1 fabrics are generally rare, due to D_2 transposition and metamorphic recrystallization. Where preserved, mesoscopic D_1 fabric elements consist of slaty cleavage, which is crenulated to form a differentiated S_2 crenulation cleavage, and a shallowly plunging volcanic-clast lineation.

The macroscopic geometry of the Wasekwan Group is the result of the D_2 overprinting of the D_1 geometry. The D_2 deformation postdates the intrusion of plutons and the Sickle Group, so the distribution of these rocks is the result of D_2 deformation alone. Fabric elements of D_2 generally represent the regional mesoscopic fabrics. A steeply north-dipping S_2 schistosity to strongly differentiated foliation is ubiquitous. It is associated with upright, shallowly plunging, tight to isoclinal F_2 folds. The shallow plunge suggests an early subhorizontal enveloping surface, which probably developed with its related fabric elements during D_1 folding and thrusting. This inference not only explains the D_2 geometry, but also provides a mechanism for the D_1 juxtaposition of the various tectonic-geochemical affinities that constitute the Wasekwan Group.

Intense D_2 deformation has produced broad zones of transposition and a composite S_2 fabric (i.e., a differentiated fabric representing the crenulation of an older fabric without the preservation of the older fabric). The D_2 deformation is interpreted

to have become more focused with time as regional shear zones developed during its the final stages. The most significant regional D_2 shear zone is the JSZ (Bateman, 1945; Milligan, 1960), which represents a major zone of ductile deformation along the southern margin of the southern Lynn Lake greenstone belt. In the central portion of the greenstone belt, the JSZ forms the boundary between the Wasekwan Group and the Pool Lake plutonic suite, as well as between stratigraphically unrelated belts of Wasekwan Group rocks. In this region, the JSZ has an anastomosing mylonitic core within a 300 m wide zone of intense crenulation cleavage. The occurrence of the JSZ along the supracrustal-plutonic contact probably reflects the localization of regional D_2 shear strain along a primary rheological boundary.

Shear zones in the western portion of the southern greenstone belt are characterized by a series of parallel high-strain zones within the Wasekwan Group. Three subparallel shear zones have been delineated west of Gemmell Lake (Fig. GS-11-1). The southernmost of these appears to be the main strike continuation of the JSZ. A second zone, parallel to the JSZ, has been delineated immediately north of Gemmell Lake and has been traced westward through intermittent outcrop north of Stear Lake. The westward continuation of this shear zone forms the Dunphy Lakes fault system (cf. Beaumont-Smith, 2000). The entire Gemmell–Dunphy Lakes zone represents a splay of the main JSZ, which bifurcates immediately east of Gemmell Lake. A third shear zone has been identified in the northern portion of the southern greenstone belt, approximately 1 km south of the northern greenstone belt margin north of Stear Lake. This shear zone, the North Stear Lake Shear Zone (NSLSZ), forms a prominent topographic linear feature, which trends subparallel to the JSZ, slightly oblique to the regional strike of the greenstone belt. The topographic linear extends south of Irene Lake through to Dunphy Lakes, where it corresponds to a 200 m wide zone of intense deformation involving Wasekwan Group sedimentary rocks and granodiorite. The eastern strike extension of this shear zone is unknown, but it does not appear to represent a JSZ splay.

In the eastern portion of the southern Lynn Lake belt, the JSZ has been traced farther to the east beyond One Island Lake. In this area, it corresponds to a series of topographic linear features, including Wetikoeekan and Adam lakes and the Barrington River north of the Eden Lake Intrusive Complex (Cameron, 1988). Limited outcrop in this area precludes precise positioning of the JSZ, but it appears to follow the supracrustal-intrusive contact and continues east beyond the greenstone belt, affecting the Barrington River megacrystic granite.

The D_2 shear zones developed in the Lynn Lake belt demonstrate very uniform kinematics, further supporting the idea that they developed in response to regional D_2 deformation. The shear zones are characterized by dextral-transcurrent shear-sense indicators on horizontal surfaces and steeply plunging, generally down-dip stretching lineations. Shear zones with similar kinematics are generally interpreted as transpressional shear zones (cf. Lin et al., 1998). Shortening normal to the shear zone is accommodated by peripheral regions, producing steeply plunging stretching lineations, whereas the transcurrent component of the deformation is accommodated by a narrow, highest strain shear-zone core characterized by shallowly plunging stretching lineations. Shallowly plunging stretching lineations have not been documented in the Lynn Lake belt. Variations in the obliquity of stretching lineations within the belt are a function of host rock, with shear zones that affect the Wasekwan Group characterized by generally down-dip (steep) stretching lineations, whereas those that affect Pool Lake suite granitoid rocks have more variable, steep to moderately plunging stretching lineations (Fig. GS-11-2). This suggests that the steep plunge of the stretching lineations may reflect a component of inheritance and incomplete reorientation during shearing of stretching lineations produced during bulk regional shortening that is associated with D_1 and the earlier stages of D_2 transpression, as opposed to their development solely in response to noncoaxial shearing.

There is mounting evidence that D_2 is responsible for the regional development of shear zones in the Lynn Lake greenstone belt. The NSLSZ is an example of a regional-scale shear zone developed in the interior of the greenstone belt, as opposed to along the margin of the belt where regional deformation is concentrated along zones of rheological contrast



Figure GS-11-2: Moderately east-plunging, oblique stretching lineations developed in mylonitized Pool Lake Plutonic suite granodiorite affected by the NSLSZ in the western Dunphy Lakes area; note pen at top of photo for scale.

between the Wasekwan Group and intrusive rocks, resulting in the development of the JSZ. The regional development of D_2 shear zones following transposition may represent a strain softening mechanism, counteracting the strain hardening effects of the continued tightening of F_1 and F_2 folds responsible for regional-scale transposition.

The D_1/D_2 geometry of the Lynn Lake belt is overprinted by a series of structures that formed during less intense phases of deformation. Although these events are penetrative at mesoscopic scale, their effect on the macroscopic geometry (map pattern) is generally minimal. Deformations D_3 and D_4 are manifested by northwest- and northeast-trending crenulation cleavage and open to closed folds, respectively. With the exception of the Boiley Lake–Counsell Lake area (see Anderson and Beaumont-Smith, GS-12, this volume) and possibly the complex dome-and-basin geometry developed in the Laurie Lake area (Zwanzig, 2000), these deformation phases been related to the distribution of units in the Lynn Lake belt. Deformation D_5 comprises a north-oriented conjugate cleavage set and open folds associated with the macroscopic warping of the greenstone belt. The final deformation (D_6) represents the brittle-ductile reactivation of D_2 shear zones, producing a variety of open to tight folds and pseudotachylite breccia zones within D_2 shear zones. The D_6 reactivation is thought to be sinistral transcurrent in nature, based on a predominance of sinistral offsets and fold asymmetry.

METAMORPHISM

The metamorphic history of the Lynn Lake belt represents a composite of two metamorphic events. Contact metamorphism, associated with the abundant intrusions of the Pool Lake plutonic suite (M_1), produced narrow upper greenschist facies aureoles that are overprinted by upper greenschist to upper amphibolite facies mineral assemblages produced during regional metamorphism (M_2). In addition to the recrystallization associated with the M_2 regional overprinting, the intense D_2 deformation that followed intrusion of the plutons has largely transposed the M_1 contact metamorphic aureoles, making identification of M_1 assemblages difficult. The M_1 assemblages are generally recognized by the growth of garnet prior to D_2 fabric development. The M_1 garnets either contain S_1 internal foliations discordant with the matrix S_2 foliation or are strongly deformed during D_2 , resulting in boudinage of the porphyroblasts or folding of elongated (stretched) porphyroblasts and their pressure shadows. Along the west shore of Eldon Lake, a particularly well exposed granodiorite contact region contains highly deformed calc-silicate, consisting of lime-green siliceous boudins in S_2 within a garnet- and diopside-rich matrix (Fig. GS-11-3).

The regional M_2 metamorphic event has produced widespread, post- D_2 recrystallization and porphyroblast growth. The M_2 porphyroblast growth both overprints and is affected by D_4 fabrics, indicating broadly syn- D_4 timing of the regional metamorphic peak. In the western portion of the greenstone belt, where the metamorphic grade reached middle to upper amphibolite facies, this has resulted in significant modification of D_2 fabric elements. Highly strained and strongly crenulated amphibolite at lower grade becomes mafic tectonite, recognized by the development of very regular differentiated layering.

SHEAR-HOSTED GOLD METALLOGENY

In conjunction with structural analysis, investigations into the origin of shear-hosted gold mineralization are critical to understanding the history of the Lynn Lake greenstone belt and the economic viability of the region. To this end, the identification and delineation of shear zones in the western and eastern portions of the Lynn Lake belt was a major focus of this year's fieldwork.

Shear-hosted gold mineralization in the southern Lynn Lake belt has been characterized by two distinct mineralization styles, based on host-rock and alteration assemblage (Beaumont-Smith, 2000). Mafic volcanic-hosted gold mineralization is



Figure GS-11-3: M_1 garnet-diopside calc-silicate developed in the contact aureole of a Pool Lake suite granodiorite at Eldon Lake.

characterized by intense silicification, biotitization and carbonatization of highly sheared mafic volcanic and volcanoclastic rocks. The alteration is broadly synshear, with gold mineralization associated with the introduction of finely disseminated pyrite in highly silicified alteration zones. Examples of this style of mineralization include the BT deposit (Peck and Eastwood, 1997; Peck et al., 1998; Beaumont-Smith and Rogge, 1999; Jones et al., 2000), which is a broad zone of silicification and alteration in the Wilmot Lake area (Beaumont-Smith, 2000). The second style of gold mineralization is hosted by highly sheared, intensely silicified and altered felsic volcanic rocks west of Gemmell Lake (Beaumont-Smith and Edwards, 2000). The mineralization is associated with very finely disseminated arsenopyrite within zones of silicification. The presence of arsenopyrite is indicated by a burnt reddish coloured bloom on weathered surfaces that has been tentatively identified as arseniosiderite.

The identification and delineation of additional D_2 shear zones in the southern Lynn Lake belt may prove significant in the search for gold mineralization. The eastward continuation of the JSZ includes a broad zone of intense silicification, biotitization and carbonatization of highly sheared mafic volcanic rocks in the Hughes River area, east of Lynn Lake. The NSLSZ represents a regionally significant shear zone, which extends west from Stear Lake to Dunphy Lakes and includes the southern Irene Lake area, an area of confirmed gold mineralization (Ferreira, 1993). The NSLSZ is neither a splay of the JSZ nor directly associated with it, and therefore demonstrates the regional development of D_2 shear zones. This shear zone hosts a zone of intense sericitization, silicification and pyritization of felsic volcanic rocks within a broader garnet-magnetite alteration zone north of Stear Lake (Fig. GS-11-4). Although analyses are pending, the intensity and style of alteration are highly prospective for gold mineralization.

Another significant finding from this summer's fieldwork is a zone of intense alteration along the western shore of Eldon Lake. The alteration is hosted by strongly deformed calc-silicate and biotite-rich, felsic volcanoclastic sedimentary rocks within the contact aureole of the Pool Lake suite granodiorite immediately to the south. The high state of strain in these rocks probably reflects the localization of regional D_2 strain in the volcanoclastic rocks, as opposed to the more competent Lynn

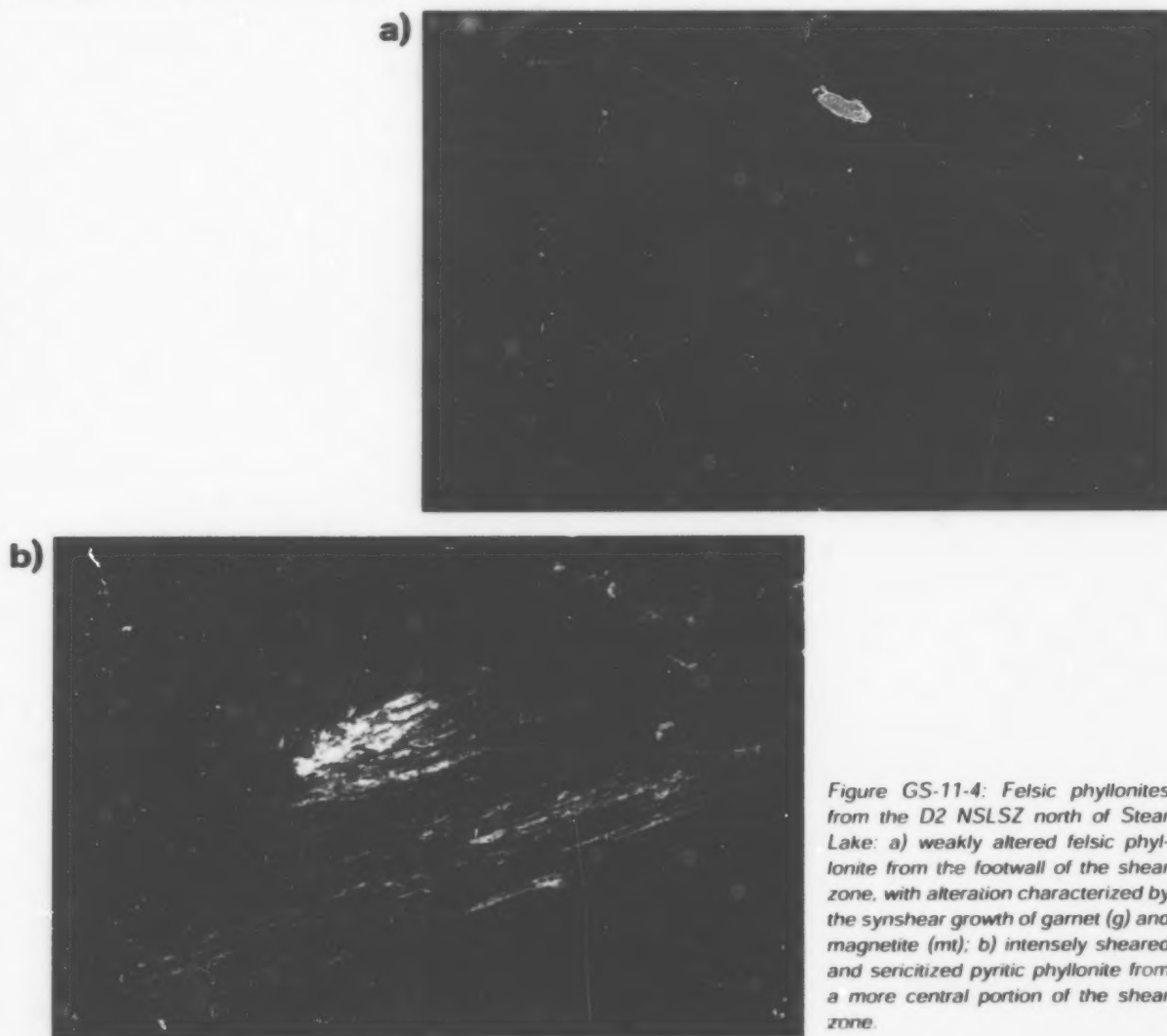


Figure GS-11-4: Felsic phyllonites from the D_2 NSLSZ north of Stear Lake: a) weakly altered felsic phyllonite from the footwall of the shear zone, with alteration characterized by the synshear growth of garnet (g) and magnetite (mt); b) intensely sheared and sericitized pyritic phyllonite from a more central portion of the shear zone.

Rhyolite to the north and granodiorite to the south. There is considerable boudinage and intercalation of units within the high-strain zone. The alteration consists of several zones of intense silicification, possibly containing fuchsite, with associated disseminated to semimassive sulphide minerals (Fig. GS-11-5). The broadest alteration zone is approximately 10 m in width. There are multiple sulphide species present, including pyrite, pyrrhotite, chalcopyrite and possibly bornite. No assay results are available, but the amount and intensity of the alteration are of considerable interest.

CONCLUSIONS

Continuing structural analysis of the southern Lynn Lake greenstone belt has provided constraints on the deformational history of the greenstone belt and identified additional prospective areas for shear-hosted gold mineralization. The early deformational history of the greenstone belt probably involved thrust imbrication and upright folding of the Wasekwan Group (D_1), followed by an intense foliation development related to transposition and shearing (D_2). These events are largely responsible for the present distribution of the greenstone rocks and explain the observed juxtaposition of the various tectonic affinities that constitute the Wasekwan Group. The D_2 deformation evolved into transpression during its later stages. Shear zones related to D_2 are more numerous and widespread than earlier thought and represent prospective targets for shear-hosted gold mineralization. Several new zones of shear-hosted alteration have been delineated in the western and eastern portions of the greenstone belt. The zones are characterized by the intense silicification of mafic and felsic volcanic rocks affected by D_2 shear zones.

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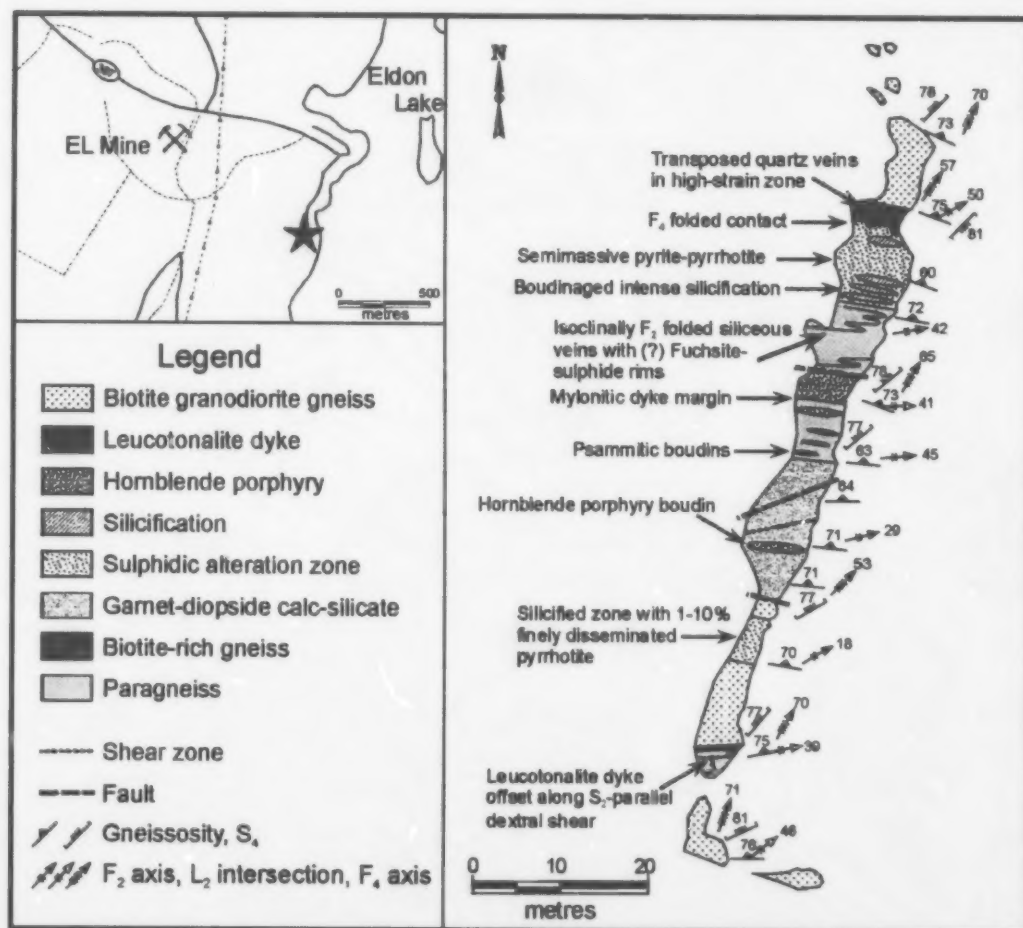


Figure GS-11-5: Sketch map showing the distribution of the intense silicification and sulphidization characterizing the Eldon Lake alteration zone.

Williams, Shoufa Lin, Dahzi Jaing and Bruno LaFrance clarified many issues during the distillation process. Robert Jones held the fort. Earl Simmons and the crew of the Manitoba Conservation warehouse in Lynn Lake provided invaluable assistance. The reviews of Herman Zwanzig greatly improved the manuscript.

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GS-12 STRUCTURAL ANALYSIS OF THE POOL LAKE-BOILEY LAKE AREA, LYNN LAKE GREENSTONE BELT (NTS 64C/11)

by S.D. Anderson and C.J. Beaumont-Smith

Anderson, S.D. and Beaumont-Smith, C.J. 2001: Structural analysis of the Pool Lake-Boiley Lake area, Lynn Lake greenstone belt (NTS 64C/11); in Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 76-85.



SUMMARY

Deformation structures along the south margin of the Johnson Shear Zone in the Pool Lake-Boiley Lake area of the Lynn Lake greenstone belt are subdivided on the basis of overprinting relationships into seven generations, which are interpreted to result from seven discrete phases of ductile (D_1 , D_2 , D_3 , D_4 and D_5), brittle-ductile (D_6), and brittle (D_7) deformation. The D_1 deformation structures are only observed in the Wasekwan Group, in accord with previous interpretations wherein the earliest deformation in the Lynn Lake belt is considered to predate intrusion of the Pool Lake plutonic suite and deposition of unconformably overlying alluvial-fluvial rocks of the Sickle Group. The D_2 deformation structures are regionally pervasive and are interpreted to record crustal-scale, dextral-oblique transpression. The Johnson Shear Zone, which hosts several significant gold deposits and showings over more than 85 km of strike length, appears to have formed as a result of partitioning of this deformation along the southern margin of the Lynn Lake greenstone belt. In the Pool Lake area, the D_2 structures are transected by a series of discrete, south-east-striking, dextral shear zones that are attributed to D_3 deformation. In contrast, D_3 structures in the Boiley Lake area occur as southeast-trending asymmetrical folds and crenulation cleavage that are consistent with F_3 folding of the Wasekwan Group into the macroscopic S-asymmetrical fold evident on regional compilation maps. The D_4 deformation structures occur as a penetrative, northeast-trending crenulation fabric associated with Z-asymmetrical, steeply northeast-plunging folds. Open folds and north-trending undifferentiated crenulations, possibly associated with the macroscopic warping of the greenstone belt, formed during D_5 deformation. These structures are cut and reactivated by a series of brittle faults and brittle-ductile shear zones that record evidence for sinistral strike-slip shear and are assigned to D_6 deformation. The D_7 deformation structures comprise a late series of north-trending, presumably brittle faults that offset the principal geological units in the west-trending Lynn Lake greenstone belt.

The D_2 shear zones in the Pool Lake area are interpreted to be second- or third-order splays flanking the Johnson Shear Zone and are therefore highly prospective exploration targets. Splay structures tend to be developed over wide areas (>5 km) along the flanks of the primary shear zone, indicating that most of the southern Lynn Lake greenstone belt should possess good exploration potential for mesothermal, shear-hosted gold deposits.

INTRODUCTION

A program of detailed (1:20 000 scale) structural mapping was initiated along the southern margin of the Johnson Shear Zone (JSZ) in the south belt of the Paleoproterozoic Lynn Lake greenstone belt (Fig. GS-12-1). The JSZ (Bateman, 1945) is a regional-scale, northerly dipping, linear deformation zone that has been traced along strike for more than 85 km and hosts several gold deposits and significant showings (Fedikow et al., 1991). The program was initiated in order to reconcile the results of regional- and detailed-scale structural analyses of the JSZ (e.g., Baldwin, 1987; Sherman et al., 1989; Fedikow et al., 1991; Peck and Eastwood, 1997; Peck et al., 1998; Beaumont-Smith and Rogge, 1999; Beaumont-Smith, 2000; Beaumont-Smith and Edwards, 2000) with regional geological patterns and structures evident along the south margin of the shear zone in the Pool Lake-Boiley Lake area (e.g., Gilbert et al., 1980, Map GP80-1-6). This mapping program is part of the ongoing, multidisciplinary, collaborative geoscience project focussed on understanding the deformation history of the JSZ and the structural controls on gold mineralization in the Lynn Lake greenstone belt.

The Pool Lake-Boiley Lake area is located approximately 18 km south-southwest of Lynn Lake. Access to the study area is provided via Provincial Road 396 and the Hudson Bay Railway line from McVeigh station. The study area has been the focus of base-metal exploration for a considerable period of time, including an active exploration program in the Boiley Lake area; as such, it is accessible by all-terrain vehicle along numerous drill roads.

GEOLOGICAL SETTING

The Paleoproterozoic Lynn Lake greenstone belt in the study area comprises metamorphosed volcanic, volcanoclastic and sedimentary rocks of the ca. 1910 Ma (Baldwin et al., 1987) Wasekwan Group, intruded by the ca. 1876 Ma (Baldwin et al., 1987) Pool Lake plutonic suite (Gilbert et al., 1980). Both of these units are unconformably overlain by fluvial-alluvial coarse clastic metasedimentary rocks of the ca. 1850 Ma Sickle Group (Norman, 1933; Gilbert et al., 1980).

Metamorphic mineral assemblages in these rocks indicate upper greenschist to middle amphibolite facies peak metamorphism. Microstructural analysis by Beaumont-Smith and Rogge (1999) indicates that the metamorphic peak was achieved subsequent to the main (D_2) phase of regional deformation.

The Wasekwan Group (Bateman, 1945) in the study area is exposed in an elongate, sinuous belt, up to 1.1 km wide, that

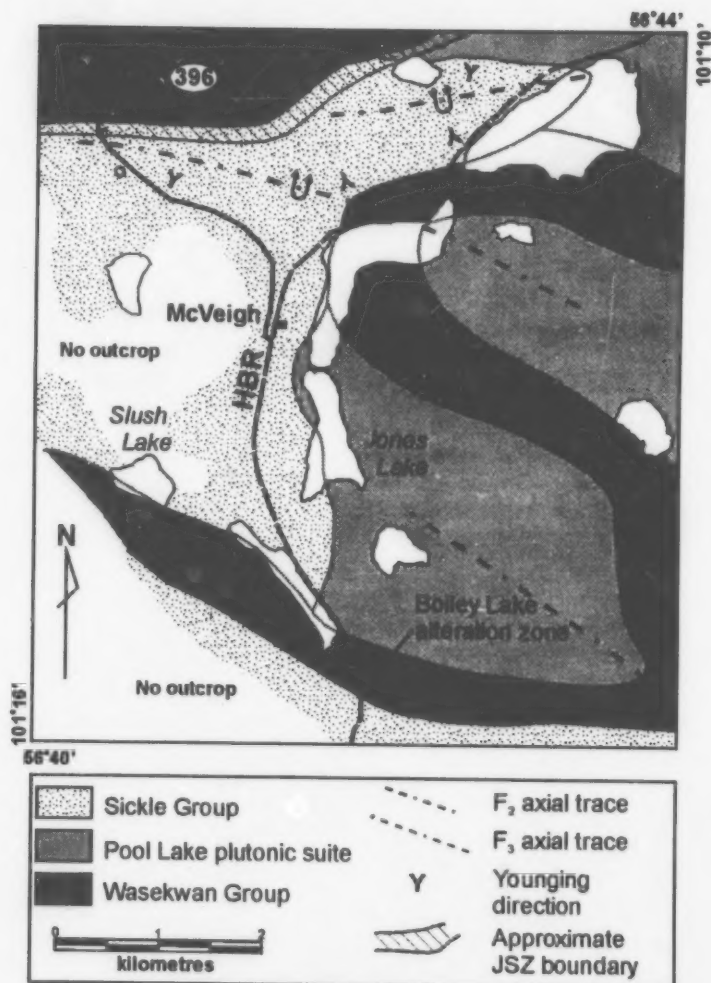


Figure GS-12-1: General geology of the southern Lynn Lake greenstone belt in the Pool Lake-Boiley Lake study area (after Gilbert et al., 1980), showing the location of the Johnson Shear Zone, the Boiley Lake alteration zone, and the axial traces of macroscopic F_2 and F_3 folds. Abbreviation: HBR, Hudson Bay Railway.

is folded into a southeast-trending, macroscopic S-asymmetrical fold along the southern margin of the greenstone belt (Fig. GS-12-1). Along the north limb of the fold in the Pool Lake area, the Wasekwan Group comprises massive and pillowed, porphyritic to aphyric mafic flows intercalated with subordinate mafic volcanoclastic rocks, epiclastic sedimentary rocks, felsic tuff and massive felsic flows. Pillowed mafic flows are particularly well preserved along the south shore of Pool Lake, where younging criteria indicate that these rocks are upright and young to the north. The stratigraphy of the southern fold limb is dominated by coarse mafic volcanoclastic breccia and epiclastic sedimentary rocks that host a distinctive, semiconformable biotite-garnet-chlorite±anthophyllite±magnetite±kyanite±staurolite±cordierite alteration zone associated with massive-sulphide mineralization (Gale, 1983; Ferreira, 1993).

The Wasekwan Group is intruded by quartz diorite plutons of the Pool Lake plutonic suite (Gilbert et al., 1980). Quartz diorite is exposed over large areas in the eastern and northeastern portions of the study area. These rocks are light grey, medium grained, equigranular and homogeneous. The contact relationships between the quartz diorite and the Wasekwan Group were not observed directly. In one location along the southeast shore of Pool Lake, however, the Wasekwan Group is intruded by quartz diorite dykes that are visually similar to the adjacent quartz diorite pluton of the Pool Lake suite.

On a regional scale, intrusion of the Pool Lake suite is constrained to predate regional D_2 deformation (Gilbert et al., 1980), since D_2 structures are well developed in the nonconformably overlying conglomerate units of the Sickie Group (see below). In the Pool Lake exposure, however, the regional S_2 fabric in the Wasekwan Group is cut at a low angle by the quartz diorite dykes. These dykes are boudinaged in S_2 and contain a weak S_2 -parallel fabric. These relationships may indicate early- to syn- D_2 intrusion of the quartz diorite dykes, or that the regional fabric is a composite S_1/S_2 .

The Sickie Group (Norman, 1933) comprises polymictic, pebble to cobble conglomerate interstratified with subordinate medium- to coarse-grained, pebbly, arkosic sandstone and rare laminated siltstone. Primary sedimentary structures, including

graded beds, trough cross-bedding, ripple cross-laminations and soft-sedimentary folding, are common. Bedding-cleavage relationships and the younging criteria greatly facilitate mapping of large-scale fold closures in the Sickie Group.

Norman (1933) proposed that the Sickie Group rests with angular unconformity on rocks of the Wasekwan Group and Pool Lake plutonic suite. The contact between the Sickie Group and quartz diorite of the Pool Lake plutonic suite is exposed along the southern edge of a large stripped outcrop approximately 1.0 km north of the southwest end of Pool Lake. As described by Milligan (1960), polymictic cobble conglomerate immediately adjacent to the contact contains several well-rounded pebbles and cobbles of quartz diorite that are identical in appearance to the adjacent, stratigraphically underlying, quartz diorite pluton.

STRUCTURAL ANALYSIS

Mesoscopic deformation structures in the Pool Lake–Boiley Lake area are subdivided on the basis of overprinting relationships into seven generations, which are interpreted to result from seven discrete phases of ductile (D_1 , D_2 , D_3 , D_4 and D_5), brittle-ductile (D_6) and brittle (D_7) deformation.

Structures attributed to D_1 deformation are only locally preserved in the Wasekwan Group in the study area, and were not observed in rocks of the Sickie Group or the Pool Lake suite. The D_1 structures comprise a penetrative S_1 foliation preserved in the hinges of F_2 folds and between S_2 crenulation cleavage planes. The S_1 foliation is defined by a preferred orientation of quartz veinlets and fine-grained biotite and amphibole (Fig. GS-12-2). The apparent absence of D_1 structures in the Sickie Group and Pool Lake suite supports previous interpretations, wherein these rocks are considered to postdate regional D_1 deformation (Gilbert et al., 1980).

Structures attributed to D_2 deformation are regionally developed in the study area (e.g., Beaumont-Smith and Rogge, 1999; Beaumont-Smith, 2000). The S_2 planar fabric is typically defined by a weak preferred orientation of amphibole and biotite in intrusive rocks of the Pool Lake suite. In the Sickie Group, S_2 is typically penetrative, finely spaced and defined by a preferred orientation of fine-grained amphibole and biotite, and flattened pebbles and cobbles in conglomerate. The S_2 planar fabric in the Wasekwan Group is defined by foliated amphibole and biotite, flattened clasts in volcanoclastic and epiclastic rocks (Fig. GS-12-3), and local strongly attenuated pillows. Typically, the S_2 foliation dips steeply north and contains a down-dip to steeply plunging mineral and stretching lineation defined by the long axis of elongate hornblende and biotite grains, and stretched clasts in fragmental rocks. The axial ratios of stretched clasts generally define oblate ellipsoids, consistent with flattening strains.

The S_2 foliation is axial planar to F_2 folds. These folds are tight to isoclinal, inclined, and upright to overturned. The F_2 folds are particularly well defined in the Sickie Group, where S_0/S_2 intersection lineations indicate that the folds plunge steeply north-northeast. Regional-scale F_2 folds with wavelengths ranging up to several kilometres appear to have been transposed along the south margin of the JSZ (Fig. GS-12-1), possibly during the later increments of progressive, ductile, dextral shearing.

The D_2 deformation in the Pool Lake area is thought to be associated with the principal phase of movement along the JSZ (Beaumont-Smith and Rogge, 1999; Beaumont-Smith, 2000). In the study area, shear zones interpreted to record high finite D_2 strain appear to be preferentially developed in Wasekwan Group mafic volcanic rocks, as well as along principal lithological contacts. The D_2 shear zones are typically less than 5 m thick and anastomose on a large scale around relatively low strain domains with well-preserved primary textures and structures. The shear zones are characterized by penetrative crenulation fabrics and mylonitic foliations, locally with well-developed ribbon mylonite and prominent tectonic layering. Isoclinal,



Figure GS-12-2: S_1 fabric, locally containing boudinaged quartz veins, overprinted by penetrative S_2 crenulation cleavage and asymmetrical F_2 folds in Wasekwan Group pillowed mafic flows, south of Pool Lake. Top is north.

Figure GS-12-3: S_2 planar fabric defined by flattened clasts in mafic fragmental rocks of the Wasekwan Group south of Pool Lake. Top is north.



rootless and intrafolial F_2 folds are common in these zones. The S_2 fabric contains a pervasive, steeply plunging L_2 mineral and stretching lineation, with local development of $L>S$ tectonites. Sense-of-shear indicators are only well developed in the Y-Z plane of the strain ellipsoid (i.e., roughly the horizontal plane). The shear-sense indicators, including S-C fabrics, porphyroclast systems, and shear bands, consistently indicate dextral shearing. This structural geometry, which is compatible with oblique transposition (e.g., Lin et al., 1998; Lin and Jiang, 2001), is similar to that observed along the main trace of the JSZ (e.g., Beaumont-Smith and Rogge, 1999; Beaumont-Smith, 2000). On this basis, the D_2 shear zones in the study area are considered to represent second- or third-order splays (e.g., Kerrich, 1989) flanking the JSZ.

In the Boiley Lake area, the F_2 folds are upright and tight to isoclinal, with steep to shallow plunges. The associated axial-planar S_2 foliation is a steeply north-dipping, spaced to penetrative crenulation cleavage reflecting varying degrees of transposition. Within the alteration zone south of Boiley Lake, D_2 transposition is best demonstrated by penetrative boudinage and isoclinal folding of quartz-epidote veins that are interpreted to have formed during subseafloor hydrothermal alteration associated with the massive-sulphide mineralization (Fig. GS-12-4).



Figure GS-12-4: Intense transposition of quartz-epidote alteration and veins by the S_2 foliation, Boiley Lake alteration zone. Pencil in bottom right corner for scale.

Beyond the influence of the JSZ in the Boiley Lake area, the penetrative S_2 transposition fabric is overprinted by folds and fabrics that are attributed to D_3 deformation. The F_3 folds are open to tight and asymmetrical, and plunge moderately to the southeast. A penetrative, steeply dipping, S_3 crenulation cleavage strikes northwest and is axial planar to the F_3 folds. Changes in the asymmetry of the mesoscopic F_3 folds and the S_2/S_3 angular relationships around the southern hinge of the macroscopic S-asymmetrical fold that dominates the map pattern in the study area (Fig. GS-12-1) indicate that it is also attributable to the F_3 fold generation. This interpretation is supported by the observation that the S_2/S_3 fabrics are overprinted by regionally penetrative, northeast-trending D_4 fabric elements. In contrast, overprinting relationships in the Pool Lake area indicate that the northern hinge of the macroscopic, S-asymmetrical fold formed during D_2 deformation. In particular, stretched pebbles and cobbles that define the S_2 fabric in the Sickie Group northwest of Monique Lake are axial planar to the S-fold, and are not folded around the northern hinge. The S_2 fabric in this location is typically overprinted by the steeply dipping, southeast-striking, penetrative S_3 crenulation cleavage, and both are cut by D_4 fabric elements. These relationships appear to indicate that the macroscopic S-fold is a composite structure, formed through F_3 refolding of the southern limb of a pre-existing, tight to isoclinal F_2 fold.

In the footwall of the JSZ in the Pool Lake area, the D_2 structures and shear zones in the Wasekwan Group and Pool Lake suite are cut by a series of discrete, less than 1.5 m thick, ductile shear zones that are also attributed to D_3 deformation. These shear zones dip steeply to the northeast and contain a penetrative mylonitic S_3 foliation defined by biotite, amphibole and chlorite. Observed S-C fabrics, asymmetrical transposition of S_2 and offset marker units consistently indicate dextral shearing. The central portions of D_3 shear zones commonly contain less than 30 cm thick, fault-fill-type quartz veins that are folded into trains of tight to isoclinal, upright, steeply plunging folds with a consistent Z-sense of asymmetry (Fig. GS-12-5). These fold trains are wrapped around by the S_3 mylonitic foliation in the centre of the D_3 shear zones. The geometry and kinematics of the D_3 shear zones are analogous to large-scale shear bands, which may have developed in the footwall of the JSZ during a late increment of progressive dextral shearing.

Ductile structures that are attributed to the D_4 deformation have a heterogeneous distribution and geometry. Typically, however, the D_4 fabric element comprises a penetrative, northeast-trending, subvertical S_4 crenulation cleavage that consistently overprints D_2 and/or D_3 structures. In D_2 shear zones in the Wasekwan Group, the S_4 crenulation cleavage is associated with trains of small-scale, northeast-trending, steeply northeast-plunging, Z-asymmetrical folds (Fig. GS-12-6). These F_4 folds are open to isoclinal in profile, and fold the S_2 mylonitic foliation. In one location at the south end of Pool Lake, the short limb of a tight, Z-asymmetrical F_4 fold is transposed by an approximately 15 cm thick ductile shear zone that dips steeply north-northwest. This shear zone contains a mylonitic fabric defined by foliated chlorite, biotite and amphibole. Well-developed S-C fabrics record dextral shearing. Along strike, beyond the influence of the F_4 fold, the shear zone clearly transposes the S_2 foliation. In D_3 shear zones, the mylonitic S_3 foliation is commonly overprinted by a north-northeast-trending, subvertical, spaced crenulation fabric that is also attributed to D_4 deformation (Fig. GS-12-7). The F_4 crenulations lack any consistent sense of asymmetry. Collectively, the geometry of the D_4 structures is interpreted to result from east-south-east-west-northwest shortening, and local reactivation of pre-existing D_2 and D_3 structures.

Structures attributed to D_5 deformation are thought to be associated with the macroscopic north-south warping of the greenstone belt that is evident on a regional scale (e.g., Gilbert et al., 1980, Map GP80-1-6). The wavelength of the warping exceeds the scale of the study area, but mesoscopic D_5 fabric elements are developed throughout the Pool Lake-Boiley Lake area. These fabric elements comprise a collection of open folds and undifferentiated crenulations that generally form north-trending conjugate sets. Rarely, D_5 strain is sufficient to produce weakly differentiated crenulation septa.

Structures assigned to the D_6 deformation are brittle-ductile in character. In Wasekwan Group rocks, these structures



Figure GS-12-5: D_3 shear zone (lower left to upper right in the photograph) crosscutting S_2 foliation in strongly deformed pillowed mafic flows of the Wasekwan Group, south of Pool Lake. The D_3 shear zone contains asymmetrical F_3 folds defined by the quartz vein, and is cut by a brittle, S_2 -parallel, sinistral D_6 fault in the upper right portion of the photograph. Top is east.

Figure GS-12-6: Train of asymmetrical F_4 folds developed in mylonitic D_2 shear zone in massive mafic flows of the Wasekwan Group, south of Pool Lake. Along strike to the east (to the right in the photograph), trains of these folds overprint a crosscutting D_3 shear zone, thereby confirming the D_4 timing of the folds. Note that the F_4 fold train is truncated below the pencil by the bounding mylonitic fabric, indicating syn- to post- D_4 reactivation of the D_2 shear fabric.



Figure GS-12-7: Penetrative, mylonitic S_2 foliation (parallel to short edge of photograph) crosscut by a discrete, dextral D_3 shear zone (from lower left to upper right of photograph as indicated by the course of the boudinaged and folded quartz vein) in pillowed mafic flows of the Wasekwan Group, south of Pool Lake. The S_3 mylonitic foliation is overprinted by a differentiated S_4 crenulation cleavage (parallel to long edge of photograph). Top is east.

comprise S_2 -parallel, brittle-ductile faults, less than 10 cm thick, that contain thin seams of cataclasite. These faults consistently record small-scale, sinistral-sense offset of transverse D_3 and D_4 structures. Irregular veins of black to purple, fine-grained to glassy pseudotachylite, observed locally in the Sickie and Wasekwan groups, may be associated with these faults (e.g., Beaumont-Smith, 2000). Northwest of Pool Lake, quartz diorite of the Pool Lake suite contains a series of spaced, less than 1 m thick, brittle-ductile shear zones that dip steeply northwest. The shear zones exhibit marked strain gradients characterized by discrete, spaced shear fractures, along the shear-zone margins, that gradationally intensify toward a central, 5 to 10 cm thick seam of ultramylonite. Asymmetrical fabrics consistently indicate sinistral shearing. The lower strain domains between the shear zones contain arrays of en échelon, locally sigmoidal, quartz-filled tension gashes. The geometry of these tension gashes with respect to the bounding shear zones indicates sinistral strike-slip shear, with a minor component of reverse dip-slip. On the basis of their sinistral kinematics and brittle-ductile style of deformation, these shear zones are correlated with the D_6 faults described above.

The latest structures (D_7) to have affected the study area were not directly observed in the field, but can be inferred from an examination of map-scale geological patterns (e.g., Gilbert et al., 1980, Map GP80-1-6). These structures comprise a late series of widely spaced, north-trending faults that truncate and offset map units along the entire east-west strike length of the Lynn Lake greenstone belt.

The sequence of deformation evident in the Pool Lake–Boiley Lake area is essentially the same as that documented along the main trace of the JSZ by Beaumont-Smith and Rogge (1999), Beaumont-Smith (2000), and Beaumont-Smith and Edwards (2000). However, the discrete D_3 shear zones observed in the Pool Lake area have not previously been documented in the Lynn Lake greenstone belt. These shear zones may have developed only in a localized structural domain in the footwall of the JSZ, possibly due to heterogeneous boundary conditions and resultant strain partitioning during progressive dextral shearing. This hypothesis could be tested through additional, detailed structural mapping along the southern margin of the JSZ.

BOILEY LAKE ALTERATION ZONE

The southern limb of the macroscopic S-fold that appears to control the distribution of the Wasekwan Group in the study area contains an extensive, semiconformable alteration zone developed within mafic volcanoclastic and epiclastic sedimentary rocks (e.g., Gale, 1983; Ferreira, 1993). The alteration zone extends discontinuously for more than 8 km between Boiley Lake and Counsell Lake (Fig. GS-12-1), and is associated with massive-sulphide mineralization.

The alteration zone comprises various mineral assemblages, including garnet-chlorite±magnetite, garnet-anthophyllite-chlorite-magnetite, and kyanite-muscovite-biotite-chlorite. The relationship between these assemblages is not fully understood, but differences in bulk rock composition are thought to be responsible for at least some of the variation. The spatial distribution of alteration assemblages is also locally influenced by subhorizontally plunging F_2 folds. In particular, the interaction of shallow F_2 enveloping surfaces with topography locally produces strike-perpendicular fold repetitions of the alteration zone, resulting in a complex, lens-like map pattern of alteration assemblages (Fig. GS-12-8).

The distinctive metamorphic mineral assemblages in the Boiley Lake area are thought to result from regional metamorphism of primary hydrothermal alteration. The metamorphism does not appear to represent a discrete thermal event, but may be a composite of contact and/or regional thermal events. This interpretation is supported by porphyroblast-matrix microstructural relationships that indicate several periods of garnet growth, consistent with protracted porphyroblastesis. The earliest period of garnet growth occurred synchronous with S_2 crenulation-cleavage development. This resulted in the growth of a large number of snowball garnets (Fig. GS-12-9). Snowball garnets are characterized by spiral inclusion trails, indicating that garnet growth involved significant synkinematic rotation of the growing porphyroblast (e.g., Williams and Jiang, 1999). A second population of garnets is characterized by porphyroblast-matrix relationships that indicate post- D_3/D_4 growth. These porphyroblasts have internal foliations continuous with the external matrix foliation and commonly overgrow F_3 and F_4 folds. This sequence of porphyroblast growth is similar to that observed elsewhere in the Lynn Lake belt (see Beaumont-Smith et al., this volume).

The spectacular snowball garnet porphyroblasts in these rocks will be the focus of a detailed petrographic and microstructural study in the near future.

IMPLICATIONS FOR GOLD EXPLORATION

The geometry and localization of lode gold deposits are strongly influenced at all scales by structure (e.g., Hodgson, 1989; Robert et al., 1994). This relationship is particularly evident in mesothermal, lode-gold districts, such as those



Figure GS-12-8: Subhorizontal F_2 fold hinges and mesoscopic across-strike repetition of garnet porphyroblastic biotite-chlorite schist, Boiley Lake alteration zone.



Figure GS-12-9: Snowball garnet porphyroblast, Boiley Lake alteration zone. Inclusion trails in this porphyroblast, as highlighted by the dark, inclusion-poor band through the centre, record approximately 180° of counter-clockwise rotation of the porphyroblast relative to the penetrative S_2 fabric in the matrix.

associated with Precambrian greenstone belts in the Canadian Shield, where the majority of the gold deposits are spatially associated with crustal-scale, brittle-ductile shear zones (e.g., Kerrich, 1989; Robert et al., 1994). These shear zones are thought to represent the primary conduits for upward-migrating, gold-bearing hydrothermal fluids derived from deep-crustal source regions (Kerrich, 1989). Within individual lode-gold districts, however, gold deposits are typically situated away from the primary shear zone and are associated with contemporaneous arrays of relatively minor, subsidiary structures (i.e., second- and third-order splays; Kerrich, 1989; Robert et al., 1994).

These observations are significant in the context of gold exploration in the Lynn Lake greenstone belt, since most of the recent exploration for mesothermal, shear-hosted gold deposits appears to have been focussed within the Agassiz Metaltect (Fedikow, 1984; Fedikow et al., 1989) and along the main trace of the JSZ. As described above, D_2 shear zones in the Pool Lake area are interpreted to be second- or third-order splays flanking the JSZ and are therefore highly prospective exploration targets. Because splay structures tend to be developed over wide areas (>5 km) along the flanks of the primary shear zone (e.g., Kerrich, 1989), most of the southern Lynn Lake greenstone belt should possess excellent exploration potential for mesothermal, shear-hosted gold deposits. Explorationists are therefore cautioned not to overlook viable, though perhaps more subtle, distal exploration targets in favour of those located along the main trace of the JSZ.

Baldwin (1987) reported the presence of free gold in foliation-parallel quartz veins cutting Pool Lake suite quartz diorite, approximately 1 km northwest of Pool Lake. This gold occurrence was re-examined in the present study and the quartz veins were found to be hosted by a discrete, brittle-ductile, sinistral-reverse shear zone (see also Sherman et al., 1988, 1989) that is attributed to the D_6 deformation phase on the basis of deformation style, kinematics and overprinting relationships with S_2 and S_3 planar fabrics. The structural setting and characteristics of the gold-bearing quartz veins indicate that the gold mineralization was synchronous with the D_6 deformation phase, in marked contrast to the inferred syn- D_2 timing of JSZ-hosted gold mineralization in the west Gemmell Lake occurrence, approximately 5 km to the west (Beaumont-Smith and Edwards, 2000), and the Burnt Timber deposit, approximately 20 km to the east (Jones et al., 2000). These relationships indicate (at least) two stages of gold mineralization in the southern Lynn Lake greenstone belt: 1) an early stage associated with ductile, dextral-transpressional D_2 shear and development of the JSZ, and; 2) a later stage associated with brittle-ductile, sinistral-transcurrent D_6 shear and reactivation of the JSZ. An example of late-stage gold mineralization is observed in the

Farley Lake deposit in the northern Lynn Lake greenstone belt, where high-grade, gold-bearing, quartz-sulphide veins were emplaced along shallowly southwest-dipping, brittle-ductile, sinistral faults that cut across D_4 fabric elements (Beaumont-Smith et al., 2000). The D_4 fabric elements described by Beaumont-Smith et al. (2000) appear to correlate with the D_5 fabric elements described in the present study, consistent with syn- D_6 (present study) timing for gold mineralization in the Farley Lake deposit.

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SUMMARY

Detailed geological mapping of the western portion of the Agassiz Metaltect near Lynn Lake has documented a proximal to distal facies change, from east to west, that is reflected in the stratigraphic constituents of the metaltect and their immediate host rocks. The proximal facies of the metaltect is represented by a relatively thick (30–300 m) succession of high-Mg-Ni-Cr basalt (picrite), greywacke, siltstone and oxide-facies iron-formation that is associated with the MacLellan gold deposit. To the west, between Francis Lake and Sheila Lake, the distal facies of the metaltect is poorly developed, consisting of a thin (<20 m), possibly discontinuous unit of picrite and intercalated sulphidic siltstone within a thick sequence of volcanogenic siltstone, sandstone and fine-grained conglomerate. The hanging wall to the facies consists of a thick sequence of heterolithic basaltic breccia, whereas the structural footwall consists of mafic and felsic volcanoclastic rocks.

Detailed structural mapping of the MacLellan gold deposit and other subeconomic deposits shows that the host rock is strongly sheared and altered, high-Mg-Ni-Cr basalt (picrite). Fabric development within the picrite is interpreted to result from intense D_2 shearing within a regional-scale shear zone that formed as a result of partitioning of regional D_2 deformation into the picrite. The gold mineralization and associated alteration are hosted within the shear zone, and have been intensely deformed. The textural relationships between deformation structures and the ore and gangue mineral assemblages suggest an epigenetic, synshear origin for the gold mineralization in the MacLellan deposit.

INTRODUCTION

The Agassiz Metaltect (Fedikow and Gale, 1982) is characterized by a unique stratigraphy highlighted by high-Mg-Ni-Cr basalt (picrite). These rocks are an important host to gold mineralization in the northern Lynn Lake greenstone belt, including the past-producing MacLellan and Farley Lake mines, the undeveloped Dot Lake and K-Zone deposits, and a number of smaller occurrences (Fedikow, 1986). The metaltect has been the target of gold exploration since the 1950s, and the focus of research regarding its geology, geochemistry and relationship to gold mineralization (Fedikow and Gale, 1982; Fedikow, 1983, 1986, 1992; Ferreira, 1986; Fedikow et al., 1991, 1996; Gagnon, 1991; Samson and Gagnon, 1995; Ferreira and Baldwin, 1997; Peck et al., 1998; Beaumont-Smith et al., 2000; Ma et al., 2000). However, the westward extension of the metaltect and the strike-parallel variations in stratigraphy are poorly understood. In addition, there has been a simmering dispute over the genesis of gold mineralization in the MacLellan deposit, with both syngenetic exhalative (Fedikow, 1986) and epigenetic (Samson and Gagnon, 1995; Samson et al., 1999) models being proposed.

In order to address these problems, detailed stratigraphic and structural analysis of the Agassiz Metaltect has been undertaken west of, and including, the MacLellan deposit. This report presents the structural and stratigraphic findings from this year's fieldwork.

GEOLOGICAL SETTING

The Lynn Lake greenstone belt consists of two west-trending, mafic volcanic-dominated supracrustal belts, termed the northern and southern belts (Gilbert et al., 1980). The Agassiz Metaltect, as defined by Fedikow and Gale (1982) and Fedikow (1986), is a unique metalliferous entity in the northern Lynn Lake greenstone belt, comprising a distinctive stratigraphic sequence as well as a zone of anomalously high strain. The Agassiz Metaltect is hosted by the Wasekwan Group (Bateman, 1945), which includes the ca. 1910 Ma (Baldwin et al., 1987) metavolcanic and subordinate metasedimentary rocks in the Lynn Lake greenstone belt. In detail, the Wasekwan Group stratigraphy comprises a diverse assemblage of lithological units with highly variable tectonostratigraphic affinities (Zwanzig et al., 1999) that were tectonically assembled prior to, or synchronous with, intrusion of the ca. 1876 Ma Pool Lake plutonic suite (Gilbert et al., 1980; Baldwin et al., 1987). These rocks were subsequently unconformably overlain by coarse alluvial-fluvial clastic sedimentary rocks of the Sickle Group (Norman, 1933). Intense deformation transposed the belt into the present, steeply north-dipping, west-striking attitude.

Overprinting relationships between structural fabric elements define six discrete deformational events (D_1 – D_6). The macroscopic distribution of major units in the Lynn Lake belt is controlled mainly by the D_1/D_2 structural geometry. The D_2 deformation is also responsible for the development of ductile shear zones, which are important hosts to gold mineralization in the Lynn Lake belt (Bateman, 1945; Milligan, 1960; Fedikow et al., 1991; Beaumont-Smith and Rogge, 1999; Beaumont-Smith, 2000; Jones et al., 2000; Ma et al., 2000). Overprinting of the D_1/D_2 structural geometry by subsequent deformations

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produced a variety of mesoscopic fabric elements, but these deformations were of insufficient intensity to significantly re-orient the pre-existing geometry.

Peak metamorphism in the Lynn Lake belt ranges, from east to west, from upper greenschist facies to middle amphibolite facies. In the area of the MacLellan deposit, metamorphic mineral assemblages indicate peak metamorphism in the lower amphibolite facies. The timing of metamorphism is relatively late in the deformational history of the area, and postdates penetrative foliations and shear zones formed during D_2 deformation. Accordingly, there is widespread recrystallization of these high-strain fabrics. The metamorphic peak is broadly coeval with northeast-trending chevron folds and crenulation cleavage that are attributed to the D_4 deformation phase.

STRATIGRAPHY OF THE AGASSIZ METALLOTECT

Examination of the Agassiz Metallotect over 65 km of strike length has resulted in the identification of stratigraphic facies changes within the metallotect and changes in the nature of the associated gold mineralization (Fedikow and Gale, 1982; Fedikow, 1983, 1986, 1992; Ferreira, 1986; Fedikow et al., 1991, 1996; Gangon, 1991; Parberry, 1991; Samson and Gagnon, 1995; Peck et al., 1998; Beaumont-Smith et al., 2000; Ma et al., 2000). Detailed geological mapping between the MacLellan deposit and Frances Lake demonstrates that there is a significant facies change from east to west, toward the western extent of the metallotect (Fig. GS-13-1). This change may represent an important control on the development of gold mineralization in the western portion of the metallotect.

Agassiz Metallotect Stratigraphy

The Agassiz Metallotect in the MacLellan mine area comprises a typical stratigraphy of picrite (high-Mg-Ni-Cr basalt), biotitic greywacke, sulphidic siltstone and oxide-facies iron-formation (Fedikow and Gale, 1982). The stratigraphic thickness of the metallotect is up to 500 m in the Farley Lake area (Peck et al., 1998; Beaumont-Smith et al., 2000) and is approximately 100 m in the MacLellan mine area. Gold mineralization that makes up the MacLellan deposit is associated with a thick unit (>30 m) of highly deformed and altered picrite. Unaltered, weakly deformed picrite is bright olive green and contains obvious pillow structures. These rocks are composed of coarse-grained actinolite (up to 5 mm) in a fine- to coarse-grained chlorite groundmass. The alteration is generally characterized by intense biotitization and silicification of the picrite, with the gold mineralization associated with the introduction of finely disseminated pyrite and lesser amounts of other sulphide minerals (Fedikow, 1986; Gagnon, 1991).

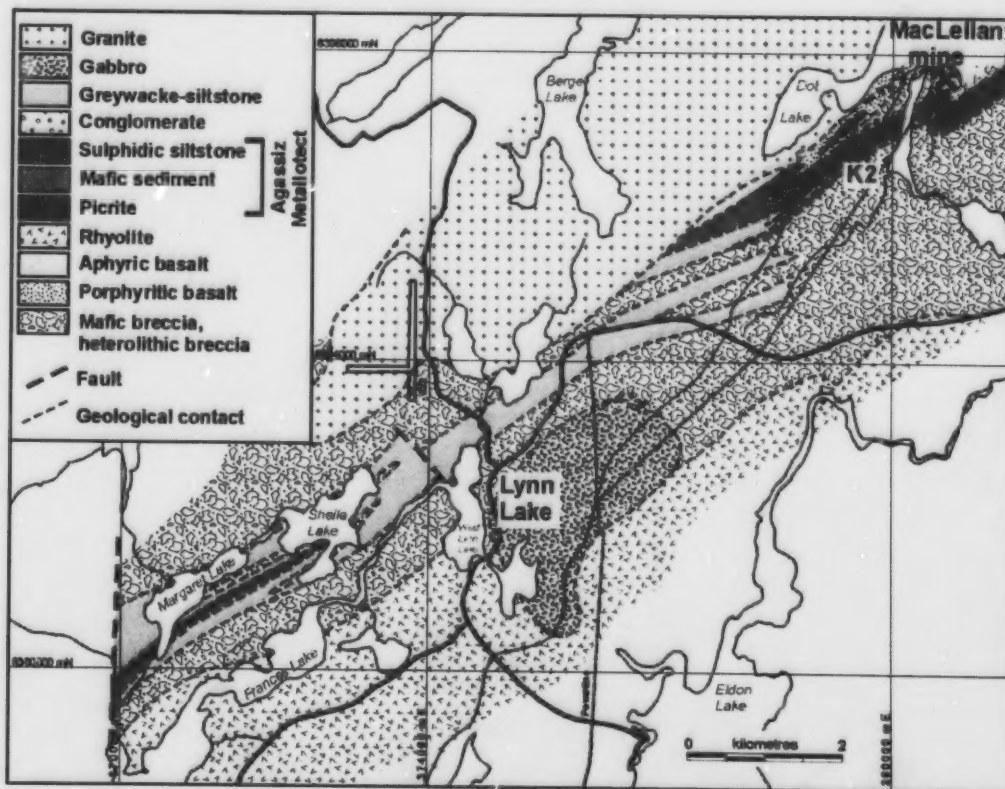


Figure GS-13-1: Geology of the MacLellan mine-Frances Lake area.

In the MacLellan mine area, the hanging wall to the metatolotect consists of high-Al, amygdaloidal, plagioclase- and/or hornblende-porphyritic to aphyric basalt. Texturally, this unit is dominated by thick volcanoclastic breccia, composed of coarse (up to 20 cm), subangular to rounded basalt clasts supported by a silty to locally plagioclase-porphyritic matrix. The breccia is weakly heterolithic, with subordinate felsic volcanic and possibly sedimentary clasts. Interlayered with the breccia are thin mafic siltstone units. This unit is interpreted as a series of proximal debris flows in the immediate mine hanging wall, with finer grained breccia units west of the mine representing more distal facies. The footwall to the metatolotect in the MacLellan mine area is poorly exposed, but appears highly variable. In the immediate mine area, the footwall consists of fragmental, porphyritic to aphyric basalt. West of the Keewatin River, the exposed footwall consists of felsic volcanoclastic rocks in the form of fine-grained breccia and laminated, coarse pebbly sandstone.

The stratigraphy of the metatolotect west of Dot Lake changes, both in terms of the stratigraphic units constituting the metatolotect and those making up the immediate hanging wall and footwall rocks. The metatolotect in the area between Frances Lake and Sheila Lake is recognized by the presence of three widely spaced outcrops of olive green picrite, and is likely 5 to 20 m in thickness. The picrite is composed of fine-grained chlorite, hornblende, plagioclase and calcite, and is strongly foliated and crenulated. Chemical analyses of the picrite in this area (Ferreira, 1986) demonstrate that it is similar in composition to picrite in the MacLellan mine area, but has slightly lower total iron and slightly higher silica and total alkali content. There is no significant alteration or sulphide mineralization, and the typical metatolotect stratigraphy is absent. In the Sheila Lake–Frances Lake area, the picrite is associated with a thick sulphidic siltstone unit but lacks the oxide-facies iron-formation that forms an important component of the metatolotect stratigraphy in the MacLellan mine area. The immediate host to the metatolotect is a thick sequence of Wasekwan Group conglomerate and siltstone. The metatolotect appears to be located along a transition zone between a sequence of psammite, coarse pebbly psammite and fine-grained conglomerate to the south, and fine-grained siltstone, garnetiferous siltstone and psammite to the north.

The thick Wasekwan Group sedimentary unit that hosts the metatolotect in the Sheila Lake–Frances Lake area is overlain by a thick sequence of mafic debris flows similar in appearance to those overlying the metatolotect in the MacLellan mine area. Rocks exposed south of the sedimentary rocks comprise a diverse stratigraphy of amygdaloidal, plagioclase-porphyritic to aphyric basalt and felsic volcanoclastic rocks. The internal stratigraphy of this sequence is not well determined but, based on the intensity of foliation development in these rocks (as elsewhere), the stratigraphic complexity may result from considerable fold intercalation and the attenuation of units along strike. These rocks are best described as S-tectonites, owing to the development of a penetrative differentiated layering. The basalt is characterized by fine, millimetre-scale, alternating hornblende- and plagioclase-rich layers, whereas the felsic volcanoclastic rocks have similar-scale alternating quartzose and biotite-hornblende-rich layers that anastomose around strongly flattened felsic clasts. The differentiated layering developed in these rocks represents the regional foliation (S_2) and is the product of amphibolite-facies metamorphic recrystallization of an original crenulation cleavage or differentiated composite foliation (Beaumont-Smith and Rogge, 1999).

Comparison of the metatolotect stratigraphy and host stratigraphy between the MacLellan mine area and the Sheila Lake–Frances Lake area poses several important questions. Of primary concern is whether the sequence of picrite and sulphidic siltstone in the western portion of the area constitutes the Agassiz Metatolotect. If so, and the westward change in metatolotect stratigraphy represents a more distal facies, does the metatolotect include the entire sedimentary succession in the Sheila Lake–Frances Lake area? It could be argued that the heterolithic mafic breccia (debris flows) overlying the sedimentary succession represents the metatolotect hanging wall, as is the case in the MacLellan mine. Similarly, the sequence of mafic and felsic metavolcanoclastic rocks exposed south of the sedimentary succession may represent the metatolotect structural footwall. These rocks are similar to those underlying the metatolotect in the MacLellan mine–Dot Lake area. Furthermore, the stratigraphy of the metatolotect, as well as large portions of the Lynn Lake belt, has been affected by intense deformation and many aspects of the stratigraphy may be deformational in origin. These questions will be addressed in future research.

STRUCTURAL ANALYSIS

Detailed structural analysis in the MacLellan mine area has defined at least six phases of deformation (D_1 – D_6), based on overprinting relationships between fabric elements. The distribution of major units is largely controlled by D_2 , which represents the most penetrative and pervasive deformation. The overprinting of D_1 fabrics by D_2 produces a steeply north-dipping regional S_2 composite foliation, resulting from D_2 transposition similar in magnitude to that documented in the southern Lynn Lake greenstone belt (Beaumont-Smith and Rogge, 1999; Beaumont-Smith, 2000; Beaumont-Smith et al., GS-11, this volume). The morphology of S_2 is variable, ranging from rare differentiated crenulation cleavage to differentiated layering, the latter representing recrystallized crenulation cleavage commonly developed in mafic volcanic rocks. Relict S_1 slaty cleavage is locally preserved in S_2 crenulation microlithons or as a slightly S_2 -oblique, clast-preferred orientation in fine-grained conglomerate beds. Transposition folds (F_2) are tight to isoclinal with shallow plunges (Fig. GS-13-2). Local style variations of F_2 folds include chevron folds and centimetre-scale crenulation folds.

Large strain gradients record the development of ductile shear zones during the late stages of the D_2 deformation. The D_2 shear zones are linear zones of intense S_2 crenulation cleavage, overprinted by an anastomosing network of ductile fabrics and isoclinal to rootless F_2 folds. The D_2 shear zones have a strong spatial relationship to picritic units in the metatolotect stratigraphy. West of the MacLellan mine, along the east shore of the Keewatin River, a pronounced D_2 strain gradient exists in the



Figure GS-13-2: Tight to isoclinal, shallowly plunging F_2 folds developed in Wasekwan Group sedimentary rocks.

structural hanging wall of the contact between the high-Al basalt and picrite. The intensity of S_2 and the tightness of F_2 folds increase toward the contact. The picrite has undergone intense deformation, characterized by shear-fabric development, which provides support for the interpretation that the picrite represents the locus of regional D_2 strain (Ma et al., 2000). The intensity of D_2 fabric development within picritic units is not uniform, as picritic rocks do not ubiquitously display shear-fabric development, but the partitioning of regional D_2 strain into picritic units does appear to be critical to the formation of the MacLellan deposit (see Ma et al., 2000).

The structural geometry of the D_2 shear zones is characterized by dextral shear-sense indicators developed on horizontal surfaces, and a steeply plunging, generally down-dip to slightly oblique (easterly pitch), stretching lineation (Fig. GS-13-3). The relationship between transcurrent shear-sense indicators and steep stretching lineations is generally interpreted as the product of transpressional deformation (Lin et al., 1998). These kinematics are similar to shear zones in the southern Lynn Lake belt (Beaumont-Smith and Rogge, 1999; Beaumont-Smith 2000), supporting the interpretation of regional D_2 shear-zone development (Beaumont-Smith, 2000).

An understanding of the relationship between shear-zone development and gold mineralization in the MacLellan gold deposit is critical to gold exploration in the northern Lynn Lake belt. Gold mineralization in the southern Lynn Lake belt is controlled by the Johnson Shear Zone (Beaumont-Smith and Rogge, 1999; Beaumont-Smith 2000; Beaumont-Smith and Edwards, 2000; Jones et al., 2000). The similarity of shear-zone timing and kinematics in the two belts presents the possibility that the metallotect-hosted gold mineralization may also reflect a genesis that depends on shear zones.

Although the gold mineralization is clearly shear hosted, various syngenetic and epigenetic origins for the mineralization have been proposed (Fedikow, 1986; Gagnon, 1991; Samson and Gagnon, 1995; Fedikow et al., 1996). A possible synshear origin is demonstrated by the relationship between shear-zone fabric development and the alteration assemblages at the MacLellan mine and the K-2 zone east of the mine. Gold mineralization at these deposits is associated with intense silicification of the picrite, largely in the form of quartz veins (Gagnon, 1991) within a broader zone of biotitization



Figure GS-13-3: Dextral D_2 S-C fabric and shear-band foliation developed in picrite at the K-2 deposit, west of the MacLellan mine.

(K-metasomatism). At the K-2 zone, the intense silicification of the picrite occurs in a variety of manifestations, representing a spectrum from narrow, variously folded and transposed quartz veinlets to massive, penetrative silicification that obliterates the deformational fabrics. The relationships between shear-zone fabrics and the degree of quartz-vein transposition indicates that the introduction of the veins clearly spans the deformation. The youngest veins are relatively weakly folded, whereas the older veins are isoclinally folded and locally form laminated lenses, reflecting their transposition during deformation (Fig. GS-13-4).

These relationships clearly demonstrate that at least a portion of the silicification is synshear in origin. The remaining question is whether the boudinaged, massively silicified zones represent a variant on the synshear, transposed, laminated veins. The evidence to date is not conclusive, but there is sufficient textural similarity between the transposed, laminated quartz veins at the K-2 zone and a large number of massively silicified zones exposed in the MacLellan crown pillar to support a synshear, epigenetic origin for the gold mineralization, as opposed to a syngenetic origin. These observations are also consistent with those of Gagnon (1991), who described a continuum in the nature of silicification from weakly folded quartz veins through transposed, laminated veins to massive silicification on the 370 m level of the MacLellan mine. The textural relationships do not address the possibility that the gold mineralization represents remobilization of syngenetic mineralization. Detailed microstructural and isotopic studies are therefore planned to help resolve this issue.

The D_2 fabric elements are overprinted by close to tight, S-asymmetrical F_3 folds and northwest-trending, axial-planar S_3 crenulation cleavage. The F_3 folds are very penetratively developed west of the MacLellan mine area, where they plunge moderately to steeply southeast. Elsewhere, D_3 fabric elements are generally rare and D_4 fabrics comprise dextral kink to chevron folds and steeply dipping, northeast-striking, axial-planar S_4 crenulation cleavage (Fig. GS-13-5). The F_4 folds plunge steeply to the northeast and are penetratively developed throughout the area. Locally, D_4 fabrics include narrow, discrete, S_4 -parallel cataclasite zones. These zones represent D_4 strain partitioning into narrow zones of dextral noncoaxial

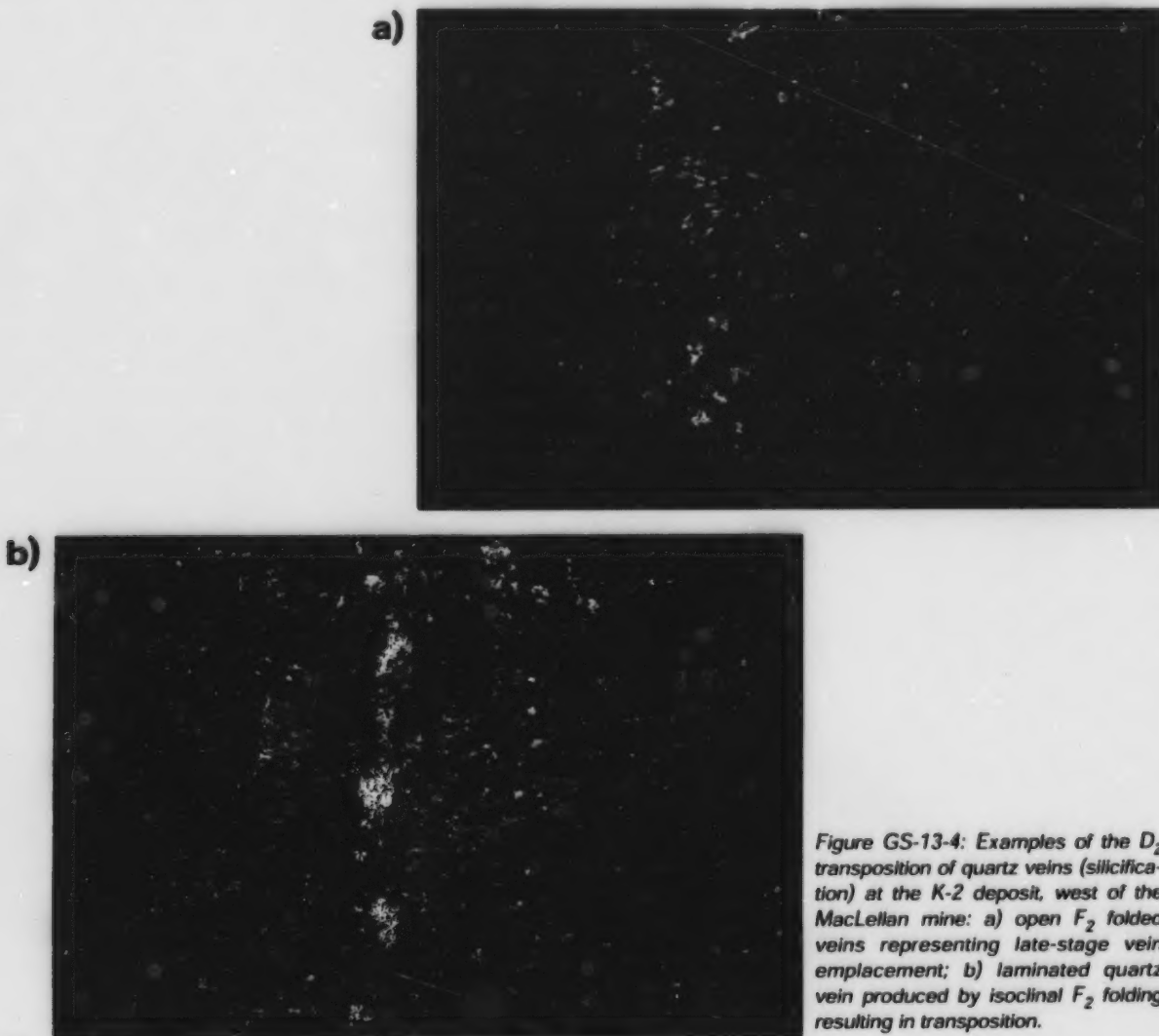


Figure GS-13-4: Examples of the D_2 transposition of quartz veins (silicification) at the K-2 deposit, west of the MacLellan mine: a) open F_2 folded veins representing late-stage vein emplacement; b) laminated quartz vein produced by isoclinal F_2 folding resulting in transposition.



Figure GS-13-5: F_2 chevron folds overprinted by Z-asymmetrical F_4 fold, Dot Lake area.

deformation, which locally produces pseudotachylite. Displacement on these zones is not significant, with displacements being limited to metre scale, and results in fabrics similar to those developed in the Pool Lake area (see Anderson et al., GS-12, this volume).

The youngest ductile deformation (D_5) produced north-trending open folds and penetrative spaced cleavages. The S_5 spaced cleavages commonly form conjugate sets and, in areas of increased intensity, form tight undifferentiated crenulations. The D_5 structures are regionally penetrative and this deformation is interpreted to be responsible for the macroscopic warping of the Lynn Lake belt, possibly resulting from east-west compression. The final deformation (D_6) is brittle-ductile, and includes development of east-trending pseudotachylite zones that overprint the older deformational fabrics (Fig. GS-13-6). This deformation is thought to represent sinistral reactivation of D_2 shear zones. Accordingly, the distribution of D_6 pseudotachylite demonstrates a strong spatial association with D_2 shear zones (Beaumont-Smith and Rogge, 1999).

The most significant change in the deformational history of the area involves the distribution of D_2 shear zones. Shear-zone development has been demonstrated to play a major role in the genesis of gold mineralization in the MacLellan mine area (Ma et al., 2000). Although the research to date has not reconciled whether the gold mineralization represents epigenetic synshear mineralization or sheared syngenetic mineralization associated with exhalative units in the metallotect, the mineralization and associated alteration are unquestionably shear hosted. The D_2 deformation west of Dot Lake is characterized by intense transposition of units, but shear-zone development has not been documented. This may reflect the decrease in the amount and strike continuity of picrite in the western portion of the area.

There is also a perceptible change from east to west in the development of fabric elements that overprint D_2 structures. Most notable is the decrease in the development of S-asymmetrical F_3 folds and S_3 crenulation in the Frances and Sheila lakes area. These fabrics represent a major control on the distribution of units immediately west of the MacLellan mine, whereas they are very poorly developed in the Sheila Lake–Frances Lake area. This results in a more linear map pattern in the western portion of the map area. The intensity of D_4 fabric development is generally consistent throughout the study area,



Figure GS-13-6: D_6 pseudotachylite zones developed in picrite and sedimentary rocks from the MacLellan mine area.

although the development of mesoscopic F_4 folds is qualitatively more penetrative to the west. Other changes include 1) a lack of calcite veinlets formed along S_5 spaced cleavage, which characterizes S_5 in the MacLellan mine area; and 2) the apparent absence of D_5 pseudotachylite zones west of Dot Lake.

CONCLUSIONS

Detailed mapping demonstrates that the Agassiz Metaltect extends west from the MacLellan mine to the Frances Lake area. The typical stratigraphy of the metaltect is largely absent west of Dot Lake, with the metaltect defined by the presence of thin picrite units within a thick unit of epiclastic sediments. The change in the nature of the metaltect may reflect a lateral facies change, with the western extension representing a more distal facies. Alternatively, the apparent discontinuous westward strike extension of the metaltect could reflect the attenuation of F_2 fold limbs during transposition, fold intercalation of units and/or (possibly) stratigraphic complexities resulting from the intersection of the shallow D_2 enveloping surface with the erosion surface. These factors could contribute to the development of a complex geometry that may result in poor strike-parallel continuity of stratigraphic units and strike-perpendicular repetitions of stratigraphy.

Detailed mapping in the main zone of the MacLellan deposit indicates that the various units making up the deposit largely represent variations in the intensity of alteration, producing different assemblages within the host picrite. The alteration is strongly deformed, commonly resulting in the boudinage of zones of silicification, which produces a lens-like distribution of alteration and mineralization. The relationship between D_2 shearing and silicification strongly suggests a synshear origin for the mineralization.

Further microstructural and geochemical analyses are planned for this year. Lead and sulphur isotope compositions are to be measured to constrain the possible source of the ore-forming fluids. Further mapping to the east of the MacLellan mine is also planned for next year, in order to determine the distribution and facies of the Agassiz Metaltect.

ACKNOWLEDGMENTS

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**GS-14 PRELIMINARY RESULTS FROM THE CHURCHILL RIVER-SOUTHERN INDIAN LAKE
TARGETED GEOSCIENCE INITIATIVE**

by D. Corrigan¹, A. Theriault¹ and N.M. Rayner¹

Corrigan, D., Theriault, A. and Rayner, N.M. 2001: Preliminary results from the Churchill River-Southern Indian Lake Targeted Geoscience Initiative; in Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 94-107.



SUMMARY

This paper reports on the first field season of a new Targeted Geoscience Initiative (TGI) aimed at providing a regional tectonostratigraphic context for supracrustal and plutonic rocks along a transect extending from the north flank of the Kiseynew Domain, through the Lynn Lake, Leaf Rapids and Southern Indian domains, to the south margin of the Wathaman-Chipewyan Batholith. It follows on from a similar transect, recently completed along the northwestern flank of the Reindeer Zone in Saskatchewan, that provided new constraints on terrane composition and assembly, and tectonic environments of formation/deposition. That transect led to the discovery of new exploration targets and renewed economic interest in the region. This field season's program included a re-evaluation of the lithotectonic framework along a transect from the northwestern margin of the Rusty Lake belt to the Partridge Breast belt, as well as a companion study on the mineral potential of the Rusty Lake belt (Barrie and Taylor, 2001).

Preliminary results show that most of the lithotectonic entities defined along Reindeer Lake in Saskatchewan can be traced with a certain degree of confidence into Manitoba. These include

- the Milton Island assemblage, a fore-arc-accretionary prism deposited on the northern flank of the La Ronge-Lynn Lake arc;
- the Crowe Island Complex, the arc's plutonic root; and
- the Park Island assemblage, a potential foreland or molasse basin.

Work in Saskatchewan has demonstrated that most of the large precollisional plutons that intrude the La Ronge Domain can be related to the Wathaman Batholith, and that together they effectively stitch the accreted supracrustal rocks to the margin of the Archean Hearne craton. We have systematically sampled volcanic and plutonic rocks for geochemical analysis and, where warranted, U-Pb dating and Sm-Nd tracer-isotope studies. Major sedimentary assemblages were also sampled for U-Pb sensitive high-resolution ion microprobe (SHRIMP) dating of detrital zircons. Analytical results will be outlined in subsequent publications.

INTRODUCTION

The Lynn Lake Multidisciplinary Geoscience Project was initiated by the Manitoba Geological Survey (MGS) in 2000, in order to provide an integrated and updated view on the regional geology and economic-mineral potential of the Lynn Lake Belt and surrounding area. In the summer of 2001, the Geological Survey of Canada joined the MGS through a new federal government Targeted Geoscience Initiative (TGI), with the specific goal of providing a regional tectonostratigraphic context for volcanic, sedimentary and plutonic assemblages that occur along a transect spanning the entire northern flank of the Trans-Hudson Orogen (THO), from the Kiseynew Domain to the Wathaman-Chipewyan Batholith (Fig. GS-14-1). This transect incorporates the better known Rusty Lake belt (which hosts the Ruttan Cu-Zn mine), part of the Lynn Lake Belt, the lesser known Partridge Breast belt and other minor supracrustal segments isolated by large intrusions.

This new TGI project covers parts of four 1:250 000 scale maps (NTS sheets 64A, 64B, 64G and 64H) and follows on from a similar, multidisciplinary, bedrock mapping project that was recently completed along Reindeer Lake in Saskatchewan (Corrigan et al., 1997, 1998a, 1998b, 1999a, 1999b, 2000; Maxeiner, 1997, 1998; Corrigan, 2000a, 2000b, 2001; Maxeiner and Demmans, 2000). The Reindeer Lake Project has yielded an improved and updated tectonostratigraphy and a better understanding of the internal framework and mutual relationships between the Kiseynew, La Ronge, Rottenstone and Peter Lake domains (Fig. GS-14-1), as well as providing new U-Pb ages and Sm-Nd tracer-isotope constraints on the nature and provenance of protoliths. One of the primary aims of the Lynn Lake Multidisciplinary Geoscience Project, and specifically of this TGI, is to complete a similar transect from the northern flank of the Kiseynew Domain, across the Lynn Lake-Leaf Rapids and Southern Indian domains, and into the southern margin of the Wathman-Chipewyan Batholith (Fig. GS-14-2). The new data will enable us to better understand the tectonostratigraphic framework and tectonic evolution of the Lynn Lake and associated belts in northern Manitoba. The ultimate integration of the results with those from the Reindeer Lake transect will further our understanding of the Trans-Hudson Orogen, provide a tectonic context for ore formation and mineralization, and permit comparisons with other known metallotects, such as the Flin Flon and Snow Lake belts.

Results presented herein highlight preliminary findings of the first of two planned field seasons. Emphasis during this field season was not particularly on systematic bedrock remapping, since it had been previously done in relative detail, but rather on the re-evaluation of lithological assemblages in terms of protolith origin, geochemical signature, isotopic age,

¹ Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8. Geological Survey of Canada contribution 20011.

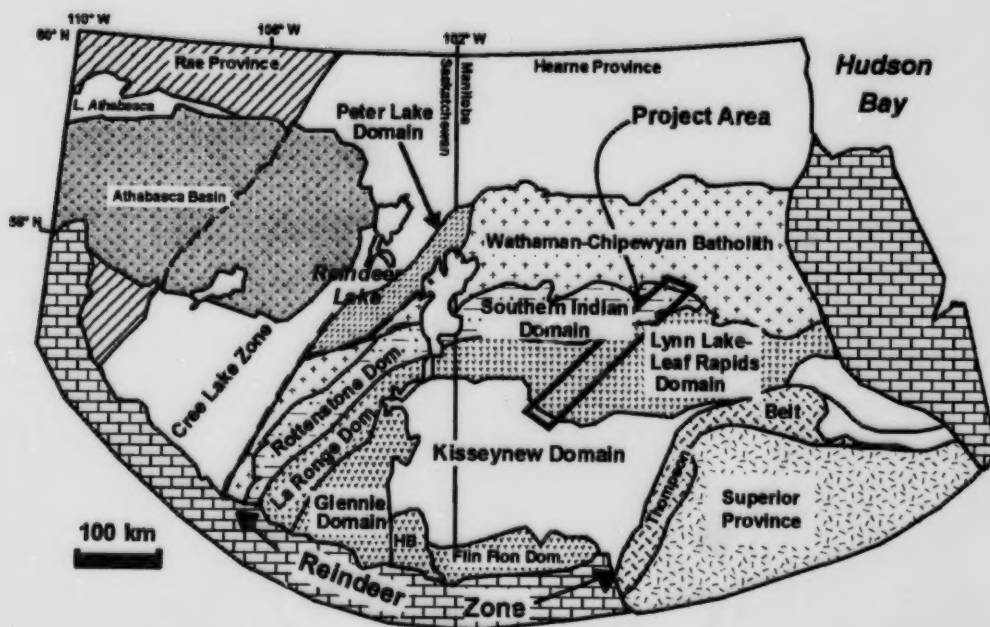


Figure GS-14-1: Main geological divisions of the Trans-Hudson Orogen in Manitoba and Saskatchewan (modified after Hoffman, 1988).

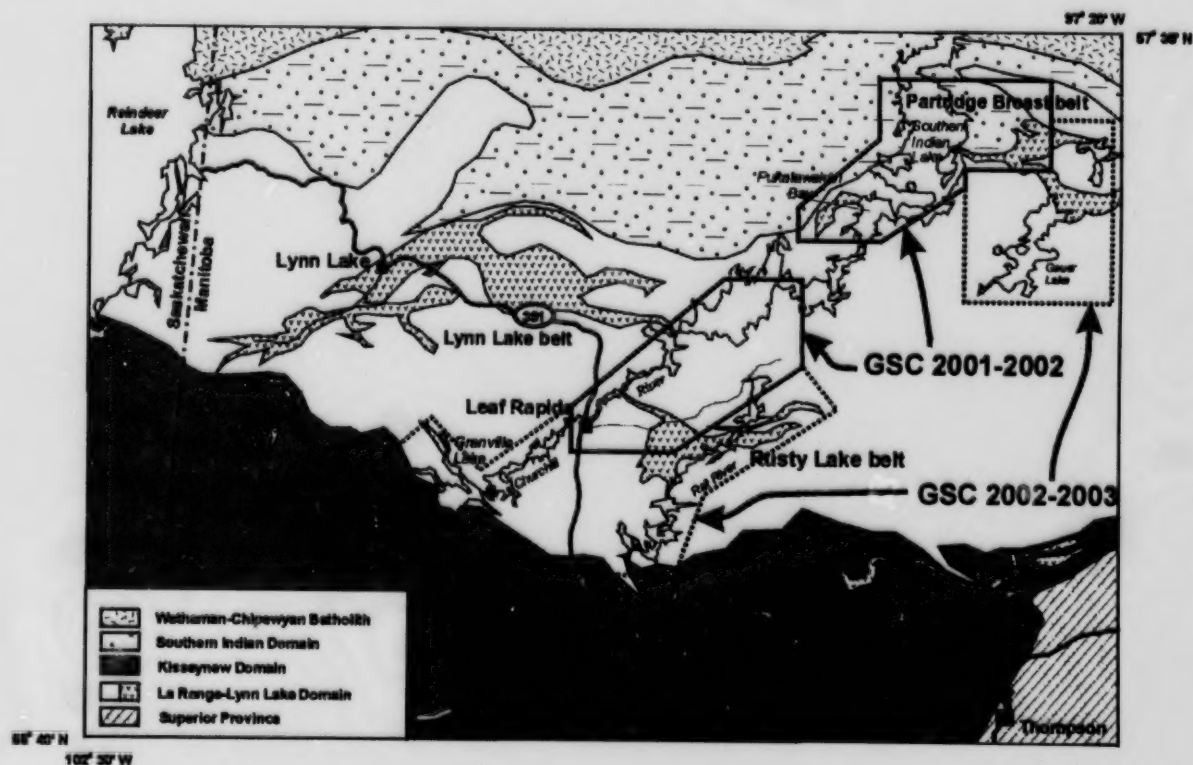


Figure GS-14-2: Simplified geology of the greater Lynn Lake area, showing the main lithological associations.

tectonic environment of emplacement/deposition and, in the case of major sedimentary units, provenance. In addition, an effort has been made to collect samples that will provide constraints on the tectonometamorphic history of the region, in order to provide an orogenic context to regional deformation. A mineral-potential study of the Rusty Lake belt is also currently underway (Barrie and Taylor, 2001). Our work 'dovetails' with detailed structural, geochronological and metallogenic studies of the Lynn Lake belt undertaken by the Manitoba Geological Survey (Beaumont-Smith and Rogge, 1999; Beaumont-Smith et al., GS-11, this volume), in collaboration with the universities of Alberta and New Brunswick, and Laurentian University. The planned fieldwork for this TGI will be completed next field season, with work being concentrated in the Granville Lake, Rat River and Gauer Lake areas. This past summer, our work covered, at various scales, an area of approximately 8000 km² and consisted mainly of traverses by boat and on foot along the shoreline and islands of the Churchill River–Southern Indian Lake system, as well as a transect, mainly by road access, across the northwestern portion of the Rusty Lake belt. The principal findings are summarized below.

REGIONAL GEOLOGY

The supracrustal and associated plutonic rocks on the northern flank of the THO in Manitoba have been previously assigned to three main lithological packages, identified as the Kiseynew, Lynn Lake–Leaf Rapids and Southern Indian domains. The Kiseynew Domain comprises mainly upper amphibolite to granulite facies metaturbidite of the Burntwood Group, which is flanked to the north by fluvial to shallow-marine, meta-arkosic and psammitic rocks of the Sickle Group. Geochronological data obtained mainly from the southern and western margins of the Kiseynew Domain constrain the age of deposition between 1850 and 1840 Ma for the Burntwood Group and 1840 and 1835 Ma for the Sickle Group (Ansdell and Yang, 1995). The structural boundary between the Burntwood and Sickle groups is also the site of a narrow but laterally continuous unit (more than 400 km in strike length) that comprises folded and boudinaged mafic flows and sills of mid-oceanic ridge basalt (MORB) affinity (Zwanzig, 2000), interlayered with calcareous psammite, metapelite and minor quartzite. This package, named the Levesque Bay assemblage in Saskatchewan (Corrigan et al., 1998b), is intruded by 1896 ± 18–16 Ma leucogranite dykes (D. Corrigan, unpublished preliminary data), suggesting that it may be either contemporaneous with, or older than, the La Ronge–Lynn Lake arc. It stratigraphically correlates with the MacLean Lake Belt in Saskatchewan (Thomas, 1993; Harper, 1998) and the Granville Lake Structural Zone in Manitoba (Zwanzig, 2000).

The Kiseynew Domain is flanked to the north by the Lynn Lake–Leaf Rapids Domain, which comprises a tectonic collage of ca. 1900 to 1880 Ma (Baldwin et al., 1987) volcanic and associated epiclastic and sedimentary rocks. Most of its tectonostratigraphic elements can be correlated with units in the La Ronge Domain in Saskatchewan (Maxeiner and Demmans, 2000). Two major volcanic belts, the Lynn Lake and Rusty Lake belts, have been identified, and each of these has been further subdivided into separate lithotectonic components and subcomponents based on geochemical signature and inferred plate-tectonic setting, including tholeiitic arc, calc-alkaline arc, MORB-like and ocean island basalt (OIB)-like rocks (Syme, 1985; Ames and Taylor, 1996; Zwanzig et al., 1999). Field relationships suggest that the various volcanosedimentary assemblages were aggregated into a tectonic collage before the emplacement of calc-alkaline plutons, which include ca. 1876 Ma gabbro stocks and tonalite (Baldwin et al., 1987).

The Southern Indian Domain flanks the Lynn Lake–Rusty Lake belt to the north and, for the most part, correlates with the Rottenstone Domain in Saskatchewan. It is dominated by foliated granitoid orthogneiss and clastic sedimentary rocks, including conglomerate, greywacke and metaturbidite, and subordinate amounts of volcanic rocks. Recent work on Reindeer Lake in Saskatchewan has led to the recognition of at least two distinct sedimentary basins in the Rottenstone Domain. They are the Milton Island assemblage (Corrigan et al., 1997), interpreted as a fore-arc or accretionary complex formed north of the advancing La Ronge–Lynn Lake arc, and the Park Island assemblage (Corrigan et al., 1998b), interpreted as forming part of a foreland or molasse basin that was deposited on the Hearne continental margin and its cover sequence as a result of tectonic loading of the La Ronge–Lynn Lake arc onto the craton. Stratigraphic equivalents of the Park Island assemblage have also been interpreted to occur in the upper sequence of the Wollaston Domain (Janice Lake assemblage; Yeo, 1998). Patterns on aeromagnetic anomaly maps suggest that both the Milton and Park Island assemblages should be expected to continue into the Southern Indian Domain.

The area north and south of the Southern Indian Domain is dominated by the voluminous Chipewyan Batholith and related Baldock and Livingston plutons. The Chipewyan Batholith is the Manitoba equivalent of the Wathaman Batholith and consists of a continental magmatic arc that was emplaced during the interval 1860 to 1850 Ma (Fumerton et al., 1984; Van Schmus and Schledewitz, 1986; Meyer et al., 1992). Compositions within the batholith range mainly from quartz diorite to syenogranite, with hornblende-biotite monzogranite being the most abundant rock type. The ca. 1855 Ma (U-Pb zircon age cited in Manitoba Energy and Mines, 1990) Baldock granite intrudes supracrustal rocks and orthogneiss of the Southern Indian Domain along its northern margin and appears to merge with the Chipewyan Batholith east of the Partridge Breast belt. It intrudes supracrustal and plutonic rocks of the Rusty Lake belt on its southern flank. The Livingston granodiorite forms another east-trending elongate pluton that intrudes the Rusty Lake belt on its northern margin and the Sickle and Burntwood groups along its southern margin. Its emplacement age is presently unconstrained.

TECTONOSTRATIGRAPHY

Leaf Rapids Domain

The Rusty Lake Belt, which forms the main supracrustal element of the Leaf Rapids Domain, has been the focus of two major studies, involving bedrock mapping and geochemical and petrological work, in the past two decades (Baldwin, 1981, 1987, 1988; Ames et al., 1990; Ames and Scoates, 1992; Ames and Taylor, 1996). Because the bedrock geology in the general vicinity of the Ruttan deposit is described in relative detail in the above publications, we decided it was unnecessary to remap the area. Instead, we have focused our attention on providing additional information by systematically sampling volcanic and plutonic rocks outside the mine area for major-, trace- and rare-earth-element geochemistry, in order to determine the nature of the source rocks and to constrain the plate-tectonic environment of formation. We have also collected samples for U-Pb geochronology and Sm-Nd tracer-isotope studies, which will provide further constraints on the absolute age of formation and model the amount of mantle-crust interaction.

Baldwin (1981) separated the Rusty Lake belt into four fault-bounded structural components named the Ruttan, Northern, Karsakuwigamak and Eastern blocks, which he interpreted as being stratigraphically unrelated. The Eastern and Ruttan blocks comprise mainly basaltic flows, with lesser amounts of mafic wacke, felsic breccia, polymictic conglomerate and minor rhyolite. The Karsakuwigamak Block contains a thick sequence of basal volcanic conglomerate, meta-arenite and psammite, which is overlain by a rhyolitic sequence comprising massive flows, brecciated flows, ignimbrites, airfall deposits, debris-flow deposits, volcanic conglomerate and meta-arenite. The Northern Block is dominated by sedimentary rocks, including a 'lower unit' of basal polymictic conglomerate and metaturbidite and an 'upper unit' of tonalite-cobble conglomerate, meta-greywacke, sulphide-facies iron-formation and iron-rich basalt. The only published age so far in the Rusty Lake belt is from a subaerial rhyolite in the Karsakuwigamak Block, dated by U-Pb zircon at 1878 ± 3 Ma (Baldwin et al., 1987). This age, which is significantly younger than the presently constrained age of volcanism in the Lynn Lake belt ($1910 \pm 15/-10$ Ma), has been used as a criterion to differentiate the Lynn Lake belt from the Rusty Lake belt.

This past summer, our work in the Rusty Lake belt was separated into two different components. The first consisted of an exploration-geochemistry study centred on the Ruttan Block, but which expanded to some of the other blocks as well. The reader is referred to Barrie and Taylor (2001) for a synopsis of preliminary findings. The second component, which is part of this study, consisted of a re-evaluation of the tectonostratigraphic and geochemical framework of the Rusty Lake belt, outside of the better studied Ruttan mine area in the Ruttan and Northern blocks. The Karsakuwigamak and Eastern blocks will be revisited and sampled next field season. Since most of our observations agreed with earlier maps, we have not deemed it worthwhile to prepare a new bedrock geological map; however, the reader is referred to Barrie and Taylor (2001) for an alternative view on the local tectonostratigraphy and relationships between the different crustal 'blocks'. In order to add constraints on the age of volcanism and sedimentation, we have sampled a quartz-feldspar porphyry rhyolite from the upper felsic and volcanoclastic unit on the Ruttan mine property, as well as a metaturbidite from the Powder Magazine formation, which sits conformably on the latter. The quartz-feldspar porphyry rhyolite will provide constraints on the U-Pb age of the youngest volcanic activity in the Ruttan Block. Analysis of detrital zircon by SHRIMP will provide constraints on the minimum age of deposition of the Powder Magazine formation, as well as on the age spectrum of source rocks.

One observation of regional significance involves the 'upper sequence' of the Northern Block (unit 'W' on Manitoba Energy and Mines, 1986). It consists of grey, tightly folded, migmatitic greywacke-turbidite with characteristic, apatite-bearing, quartzofeldspathic and quartz-rich leucosome separated from the paleosome by thin, biotite-rich melanosome. It stratigraphically overlies volcanic and volcanoclastic units of the Northern Block and is intruded by amphibolite dykes, as well as by the Chipewyan-age Baldock granite. Its stratigraphic position above the volcanic rocks, its array of metamorphic textures and composition, and its relationship with intrusive units are all very reminiscent of the Milton Island assemblage, which sits in a similar tectonostratigraphic position with respect to the La Ronge volcanic assemblage in Saskatchewan (Corrigan et al., 1997). We have sampled this unit for U-Pb SHRIMP geochronology in order to test this hypothesis, and to compare with data from the Milton Island assemblage (Ansdell et al., 1999).

Another aspect of the Leaf Rapids Domain that we examined this past field season was its tectonomagmatic evolution. The objective of this study is to determine whether more than one plutonic suite exists and, if so, to which tectonic event(s) they can be correlated. Evidence so far suggests that at least some of the gabbroic and granitic rocks associated with the Rusty Lake belt are contemporaneous with volcanism (Baldwin et al., 1987; Ames and Taylor, 1996). There is also evidence that the Baldock and other large K-feldspar megacrystic intrusions may be related to the Chipewyan suite. However, other intrusions or intrusive complexes of different relative ages and tectonic settings may be present as well. They include a strongly foliated, migmatitic diorite to granite orthogneiss complex identified on roadside outcrops south of Issett Lake, as well as large, virtually undeformed and nonrecrystallized monzogranitic plutons of potential syn- to postcollisional age. Representative samples of all the above suites and potential suites have been collected for systematic geochemical studies, as well as targeted U-Pb zircon dating and Sm-Nd isotopic characterization.

SOUTHERN INDIAN DOMAIN

Most of the mapping effort in the Southern Indian Domain was concentrated on Southern Indian Lake, where two of the

domain's most important and regionally lesser known supracrustal components occur (Fig. GS-14-3). One of the targeted areas was the Pukatawakan Bay area, which lies on the western shore of Southern Indian Lake and was mapped previously by Frohlinger and Cranstone (1972). The other was the Missi Falls-Partridge Breast Lake area, located on the eastern shore of Southern Indian Lake and extending inland along the lower Churchill River (Fig. GS-14-2). It had been previously mapped at reconnaissance scale (see Lenton and Corkery, 1981). The intervening area, underlain mainly by large felsic plutons, was also examined, but in lesser detail.

Pukatawakan Bay

The occurrence of mafic volcanic rocks with locally preserved pillow structures had been previously described from a relatively small occurrence of supracrustal rocks in the Pukatawakan Bay area (named here the 'Pukatawakan belt', for geographic reference). This summer we revisited the area with the intention of documenting the various metavolcanic rocks and associated sedimentary rocks, including small units of meta-arkosic and related fluviodeltaic rocks that had been historically linked with the Sickle Group. As well, plutons and other intrusive rocks were examined to provide constraints on the local and regional magmatic evolution.

The most lithologically complex and potentially oldest component in this region is a heterogeneous unit of migmatitic orthogneiss and paragneiss that includes predominantly metapelite and metagreywacke, interlayered with metaplutonic sheets of amphibolitic (metagabbro) to syenogranitic composition. Both ortho- and paragneiss are generally interlayered at outcrop scale and transposed parallel to the regional east-west foliation. This gneissic unit, which is relatively well exposed on the shoreline of Long Point, contains metapelitic diatexite and locally hosts partially retrograded mafic granulite boudins (Fig. GS-14-4), suggesting a metamorphic high (of unknown age) in the immediate area. The field relationship between the gneissic unit and the metavolcanic rocks could not be established due to lack of exposure. However, the fact that the gneiss assemblage reached granulite facies whereas the metavolcanic rocks are only middle-amphibolite facies, in the absence of a major shear zone, suggests that the gneissic rocks may be older. There is, as yet, no absolute age control on this unit.

On the structural top of the north-dipping gneissic unit lies a narrow layer (a few tens of metres) of amphibolite-facies garnet-sillimanite-biotite metapelite. This unit is conformably overlain by black, amphibolite-facies mafic metavolcanic rocks with locally recognizable pillow structures (Fig. GS-14-5) that suggest younging to the north, up the structural section. The mafic volcanic rocks are, for the most part, riddled with veins along which severe calc-silicate alteration occurred. On most outcrops, the calc-silicate alteration veins were subsequently transposed and now form bands that are parallel to the regional foliation, giving the rock a particular light green and black, striped or patchy appearance. Similar rocks are common in the La Ronge belt and Levesque Bay assemblage, where they represent altered, deformed and metamorphosed basaltic flows and sills. More commonly, volcanogenic amphibolite in the Pukatawakan Bay area occurs in banded gneiss, interlayered with metasedimentary rock of psammitic composition, narrow sulphide- and silicate-facies iron-formation, and fine-grained rock of intermediate composition that may represent either deformed and metamorphosed volcanic layers or transposed subvolcanic intrusions. In areas of lower strain, dykes of mixed andesite and quartz-feldspar porphyry granite are observed cutting the mafic volcanic rocks, suggesting that they are indeed subvolcanic intrusions. We sampled one of these dykes for U-Pb geochronology in order to constrain the minimum age of mafic volcanism and the age of potential feeder dykes. Elongate, dark green gabbro sills or dykes intrude the mafic volcanic rocks and associated sediments. All of the above were systematically sampled for major-, trace- and rare-earth-element analysis.

Another distinct sedimentary rock unit that occurs in the Pukatawakan Bay area consists of pink to pale beige meta-arenite and calcarenite. These magnetite-bearing metasedimentary rocks preserve many primary features, such as compositional banding, laminated beds and crossbeds, and have historically been interpreted as potential Sickle Group equivalents. In the Pukatawakan Bay area, they are uniquely preserved as small screens and enclaves in megacrystic biotite±hornblende monzogranite (Fig. GS-14-6). It is noteworthy that this arkosic suite sits at a similar tectonostratigraphic level as, and is compositionally similar to, the Park Island assemblage of the Reindeer Lake area, which yielded detrital zircon ages suggesting a predominant detrital source from the La Ronge belt (Corrigan, unpublished data).

The gneissic and supracrustal rocks of the Pukatawakan Belt are intruded by a number of plutons that are likely related to the Wathaman-Chipewyan suite. These form large, compositionally homogeneous and nonmigmatitic bodies that range in composition from gabbroic to monzodioritic to syenogranitic, but consist mainly of coarse-grained to K-feldspar megacrystic, hornblende-bearing monzogranite. They can generally be distinguished from older suites by the local preservation of relict igneous minerals and general absence of migmatitic textures. Although none of the local intrusions have been dated, most are similar in texture and composition to plutonic rocks from the Big Sand Lake area, about 60 km northwest of Pukatawakan Bay, which yielded U-Pb zircon ages of 1857 ± 9 Ma and 1854 ± 12 Ma (Van Schmus and Schledewitz, 1986). One large, gabbroic to monzodioritic intrusion related to this suite, located between Pukatawakan Bay and Whyne Bay, locally contains up to 2% disseminated chalcopyrite and pyrite. In order to constrain the absolute age of this plutonic suite, as well as provide a minimum age for the meta-arkosic unit, we sampled the K-feldspar megacrystic monzogranite on the west shore of Whyne Bay, where it contains numerous, large, meta-arkose rafts.

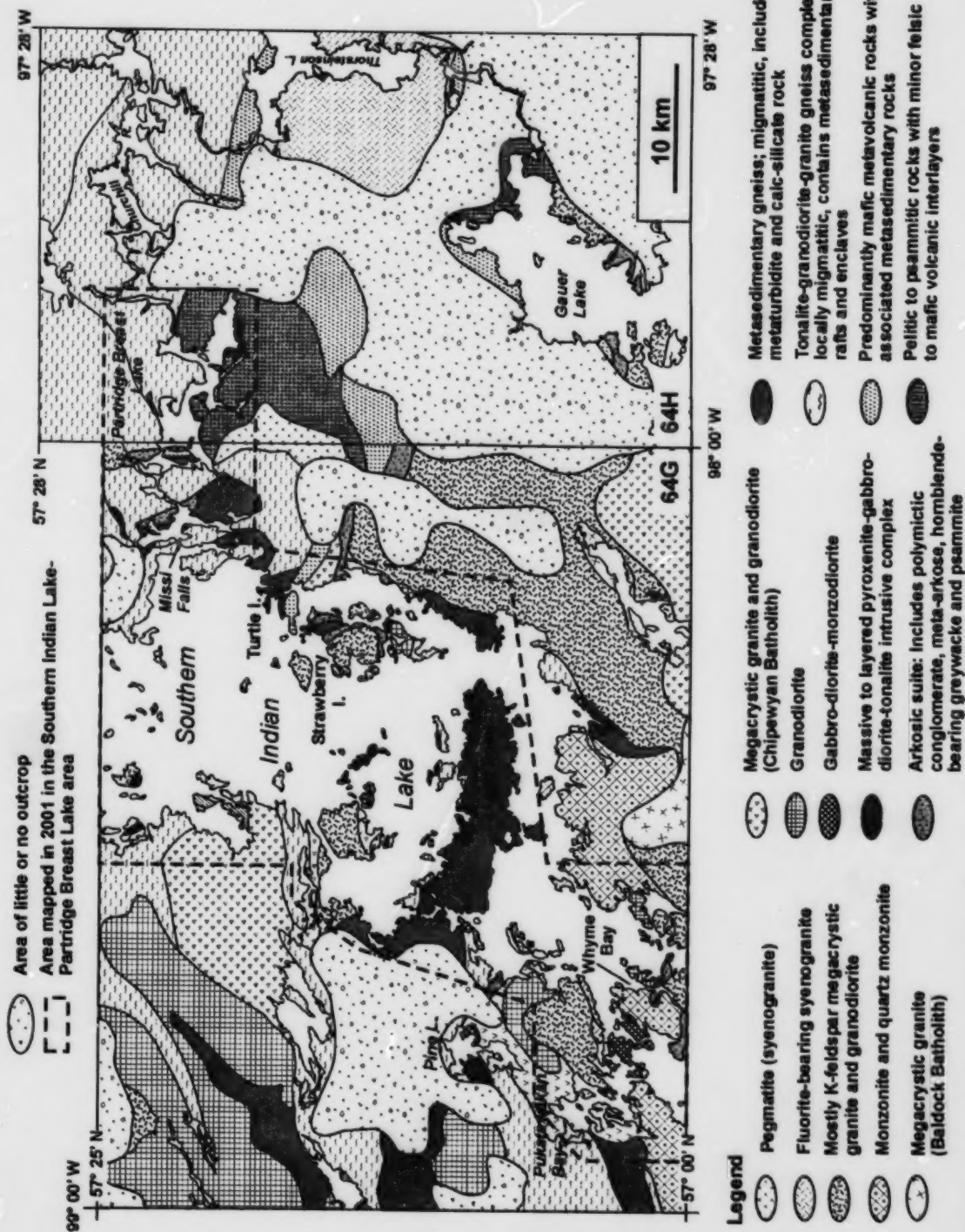


Figure GS-14-3: Simplified geology of the Pukatawagan Bay-Partridge Breast Lake area (modified from Manitoba Energy and Mines, 1987, 1990). Asymmetrical Z-fold formed by D² dextral movement along the Johnson Shear Zone.

Figure GS-14-4: Boudins of mafic granulite (small fragments next to hammer) and garnet-clinopyroxene rock in a diatexitic metapelite matrix, north shore of Long Point.

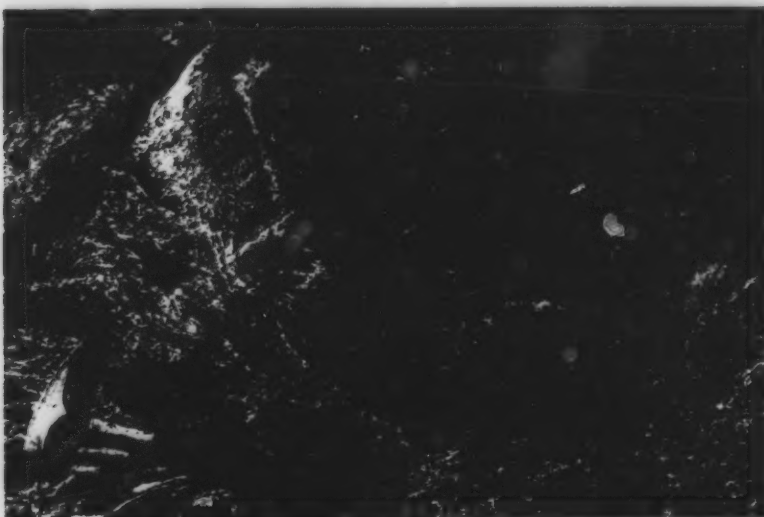
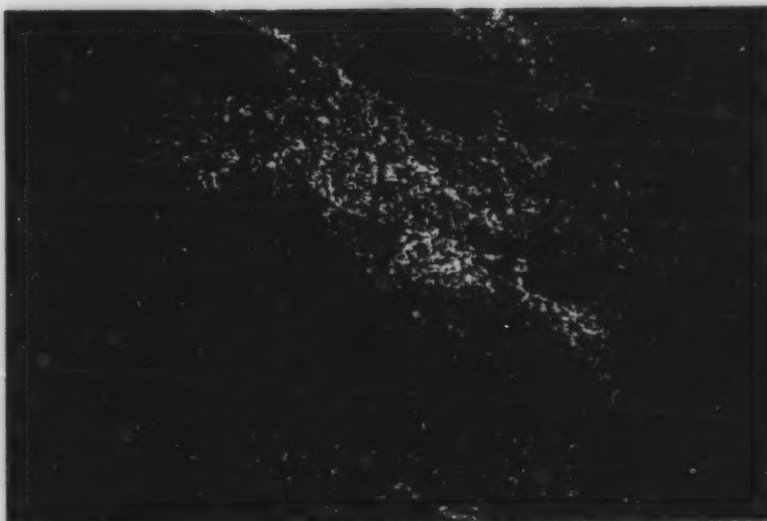


Figure GS-14-5: Pillow structures in mafic volcanic rocks of the Pukatawakan belt; light patches and streaks represent calc-silicate alteration; pencil for scale.

Figure GS-14-6: Coarse-grained hornblende monzogranite intruding laminated meta-arkose, western shore of Whyne Bay; pocket knife for scale.



Missi Falls-Partridge Breast Lake Area

The Partridge Breast belt, which outcrops east of Southern Indian Lake, mainly between the Churchill River and Gauer Lake, contains the largest volume of rocks of probable volcanic origin in the Southern Indian Domain. This past field season, we examined in detail exposures of supracrustal and associated rocks on the well-exposed shoreline and islands of Southern Indian Lake and on the lower Churchill River system, from Southern Indian Lake to the east end of Partridge Breast Lake. The area had been previously mapped at reconnaissance scale and is described in reports by Cranstone (1972) and Lenton and Corkery (1981). In essence, the local geology can be subdivided into three rock associations of differing compositions and ages.

One of the three 'packages', named herein the 'Missi Falls gneiss association' consists mainly of banded orthogneiss of tonalitic, trondhjemitic, granodioritic and syenogranitic composition. The orthogneiss is generally well foliated and completely recrystallized (Fig. GS-14-7), with local development of partial melt.

Interestingly, some of the syenogranitic components, as well as granitic pegmatite bodies, host large faserkiesel (knots of fibrolite+K-feldspar+quartz+magnetite) that are deformed into flat ellipses. The faserkiesel-bearing syenogranitic gneiss bears a strong resemblance to some portions of the Sickie meta-arkose, and could be easily misinterpreted for the latter. In this case, however, the syenogranite, as well as granitic pegmatite bodies intruding the latter, are clearly of plutonic origin, suggesting that the faserkiesel, some reaching 6 cm in length, are likely of metasomatic origin. The orthogneiss package contains inclusions of, and is structurally concordant with, clastic metasedimentary rocks dominated by migmatitic metapelite with a garnet+biotite+K-feldspar±sillimanite±cordierite±melt assemblage. All of the above are intruded by amphibolite, pyroxenite and syenogranite dykes that are now transposed subparallel to the regional foliation. A monzogranite from the Missi Falls gneiss association has been sampled for U-Pb zircon dating and Sm-Nd isotopic-tracer studies. Its contact with supracrustal rocks of the Partridge Breast Belt is not exposed. A similar dioritic to granitic orthogneiss assemblage was identified in the Southern Indian Domain extension in Saskatchewan (Rottenstone Domain) and named the 'Crowe Island Complex' (Corrigan et al., 1997).

The second distinct lithological 'package' consists of predominantly mafic volcanic rocks with minor intermediate and felsic components, associated with clastic sedimentary rocks. This package forms the dominant rock type in the Partridge Breast Belt and is intruded by altered, elongated, dioritic to metagabbroic bodies. A thick sequence of mafic volcanic rocks occurs on Turtle Island and extends inland on the eastern shore of Southern Indian Lake. It is fine to medium grained, dark green to black and highly strained, and locally contains thin dark rinds interpreted as transposed pillow selvages. Calc-silicate alteration is widespread, giving the rock a characteristic light green and black banded appearance. This rock is structurally overlain by pink to grey meta-arkose and polymictic conglomerate, although the contact between the two units is not exposed and indicators of younging direction have not been observed. The polymictic conglomerate contains mostly fine- to medium-grained, pebble- to cobble-sized, granitic to syenitic clasts (Fig. GS-14-8). The overall range in composition and textures in the mafic volcanic rocks, and the presence of meta-arkosic rocks and conglomerate immediately to the south of these, are reminiscent of the same association in the Pukatawakan Bay area, suggesting a continuity, albeit disrupted by later plutonism.

Volcanic rocks are also well exposed on a large island at the eastern end of Partridge Breast Lake. At that location, two distinct north-trending basaltic flows, with individual thicknesses of approximately 5 and 20 m, appear to sit concordantly within a heterogeneous metasedimentary assemblage that includes metapelite, crossbedded meta-arkose, thin polymictic conglomerate and debris flows. The westernmost of the two mafic volcanic layers contains abundant carbonate alteration, whereas the easternmost flow is highly silicified, giving the mafic rock a more 'felsic appearance'. The debris flow contains subangular, boulder-sized and smaller fragments of volcanic and volcanoclastic rocks of mafic to intermediate composition

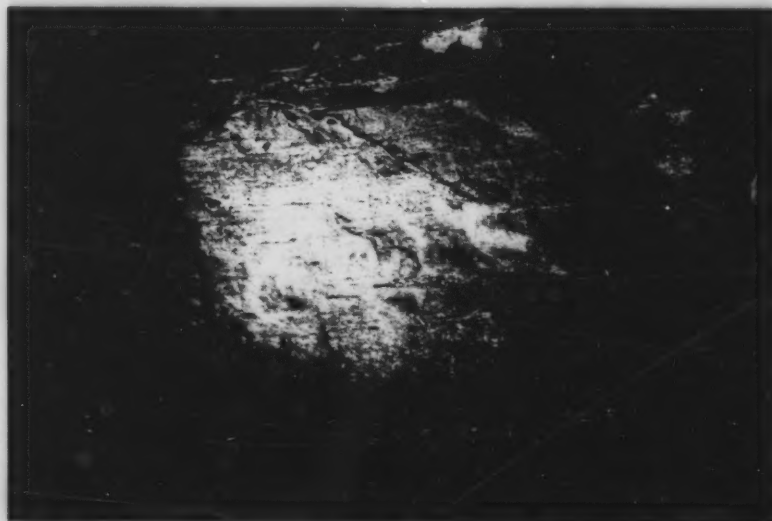
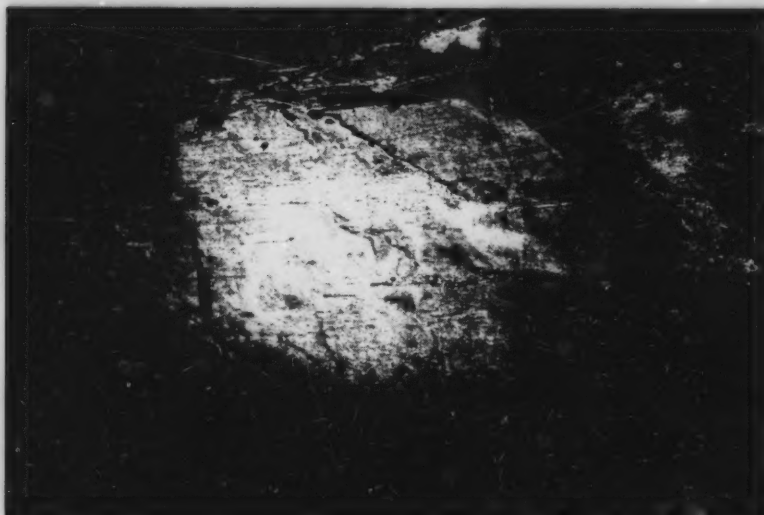


Figure GS-14-7: Highly strained, banded granite and tonalite from the Missi Falls gneiss association intruded by megacrystic granite, south shore of large island east of Bear Narrows, Southern Indian Lake; photographed area is about 2 m across.

Figure GS-14-8: Polymictic conglomerate with subangular to subrounded felsic clasts, north shore of Strawberry Island; pencil for scale. Bear Narrows, Southern Indian Lake; photographed area is about 2 m across.



(Fig. GS-14-9). Although poorly preserved, features resembling pillow keels suggest that tops are toward the west. The metavolcanic rocks are associated with metaturbidite that contains metapelitic layers bearing orthogonal fibrolite clots up to 6 cm long and 2 cm across, which appear to pseudomorph andalusite porphyroblasts. This would suggest that an earlier metamorphism at low pressure and temperature was followed by a second metamorphic event at medium pressure and temperature.

Thick sequences of pink to grey, polymictic conglomerate interlayered with metapsammite also occur within this assemblage, either as thin layers interbedded with the volcanic rocks or as relatively thick sequences near the stratigraphic top (see also Lenton and Corkery, 1981). Rock fragments in the conglomerate are subrounded to well rounded and are mainly of fine-grained meta-igneous origin. The precise contact between the thick conglomerate sequence and the mafic volcanic rocks is not exposed, but both rock units are subparallel and occur within a few metres of each other. The absence of an intervening shear zone or fault suggests a conformable relationship between the two.

The third lithological 'association' in the Missi Falls-Partridge Breast belt area consists of post- D_1 plutons that intrude the Missi Falls gneiss association and Partridge Breast belt supracrustal rocks: Two different 'suites' are noted. One suite (unit 'D' on Manitoba Energy and Mines, 1987, 1990) consists of intensely stretched ($L \gg S$), mixed intrusions of ultramafic to tonalitic composition that occur in the form of small to medium plutons, sills and dykes. One of the better exposed of these occurs on the north shore of Turtle Island (Fig. GS-14-3), where it intrudes metapelitic rocks of the Partridge Breast belt. It contains recrystallized but relatively well preserved igneous layering on a metre to centimetre scale, with individual layer compositions including pyroxenite-hornblende, metagabbro, leucogabbro, diorite, quartz diorite and tonalite. There is local evidence for multiple injection in a dynamic magma chamber, as indicated by the presence of pseudocrossbeds in rhythmically layered diorite (Fig. GS-14-10), numerous angular mafic to ultramafic xenoliths in intrusions cutting the layering (Fig. GS-14-11), and the local presence of a fine network of ultramafic veinlets cutting earlier fabrics. Metagabbroic and meta-dioritic plutons and sills also intrude supracrustal rocks in the Partridge Breast Lake area and contain a similar $L \gg S$ fabric,



Figure GS-14-9: Large clast of felsic tuff-breccia in debris-flow horizon immediately below a mafic flow, north shore of island on the west side of Partridge Breast Lake; hammer for scale.

suggesting a possible link with the Turtle Island pluton and other local intrusions. In addition to systematic sampling for geochemical analysis, a quartz diorite from the Turtle Island pluton was sampled for U-Pb geochronology. For reference, we have unofficially named this suite the 'Turtle Island suite'.

The other 'suite' consists of much larger, more compositionally homogeneous, coarse-grained to K-feldspar megacrystic, biotite±hornblende monzodiorite plutons (Fig. GS-14-12). They generally preserve a large proportion of igneous minerals and are not as strongly lineated as the 'Turtle Island suite'. Their textural, compositional and structural similarity to plutons of the Chipewyan Batholith suggests that they likely belong to that suite. Representative samples were collected for geochemical characterization.

DISCUSSION

Field observations this past season have enabled us to gain a better understanding of the tectonostratigraphic framework of the Leaf Rapids and Southern Indian domains, as well as establish specific links with components of the La Ronge and Rottenstone domains in Saskatchewan. Based on a single U-Pb analysis in each of the Rusty Lake and Lynn Lake belts, they had been interpreted as totally separate entities (i.e., Baldwin et al., 1987). However, caution should be exercised in attributing too much weight to the radiogenic ages until more become available. Our preliminary observations suggest that the belts may not necessarily be exotic with respect to one another. For example, in a recent study, Maxeiner and Demmans (2000) demonstrated continuity of the Lynn Lake and La Ronge belts, which also implies that the Milton Island assemblage, a fore-arc and/or accretionary complex that flanks the La Ronge Belt to the north, should likely have a lithological equivalent in Manitoba. A potential candidate that bears many lithological and tectonostratigraphic similarities to the Milton Island assemblage is the Zed Lake assemblage, which flanks metavolcanic rocks of the Lynn Lake Belt to the north (Gilbert et al., 1980). As previously mentioned (see 'Leaf Rapids Domain' section), the 'upper sequence' of the Northern Block also shares many similarities with the Milton Island assemblage, providing a potential link and perhaps establishing regional continuity.

Preliminary investigations of supracrustal assemblages in the Pukatawakan Bay and Missi Falls-Partridge Breast Lake areas have also yielded important observations on their respective stratigraphies and potential links. Volcanic rocks from Pukatawakan Bay and the Partridge Breast belt have many similarities and very likely represent lateral equivalents, although disrupted by Chipewyan-age plutonism. They are mainly represented by basaltic flows and show similar calc-silicate alteration, except for the one flow on Partridge Breast Lake that has undergone silicate alteration. Felsic to intermediate components do occur but are relatively rare. The stratigraphic interlayering of the mafic volcanic units with crossbedded meta-arkose, psammite and predominantly quartzofeldspathic polymictic conglomerate, however, distinguishes this volcanic sequence from those of the La Ronge-Lynn Lake arc, which are predominantly associated with deep-marine sediments and iron-formation. Systematic sampling of mafic volcanic rocks for geochemical analysis will permit comparisons among the various belts.

Historically, meta-arkose and conglomerate from the Pukatawakan Bay and Partridge Breast belt area had been tentatively named 'Sickle-type' (Cranstone, 1972). A direct correlation with the Sickle Group had been questioned by Lenton and Corkery (1981), who preferred to use the term 'arkosic suite' until an unequivocal correlation is established. According to compilation maps NTS 64F and 64G (Manitoba Energy and Mines, 1989, 1990), the 'arkosic suite' is interpreted to occur, although discontinuously, throughout the Southern Indian Domain as far west as Reindeer Lake. At that location, it correlates with the Park Island assemblage, whose deposition was constrained by U-Pb zircon dating at ca. 1870 to 1860 Ma, with the minimum age provided by the crosscutting Wathaman Batholith (Corrigan et al., 1999b). In the Pukatawakan Bay area, 'Chipewyan-type' plutons intrude rocks of the 'arkosic suite', indicating a more likely correlation with the Park Island assemblage instead of the ca. 1840 to 1830 Ma Sickle Group.



Figure GS-14-10: Rhythmic igneous layering in metamorphosed gabbro-leucogabbro, north shore of Turtle Island, Southern Indian Lake; note the disrupted layering and cross-bedded effect just below the geological hammer.

Figure GS-14-11: Angular xenoliths of pyroxenite (dark) and diorite (light grey) in a homogeneous metagabbro dyke cutting rhythmic layering (not shown), north shore of Turtle Island, Southern Indian Lake; light-coloured lines oriented subparallel to the hammer handle are glacial striations; hammer for scale.

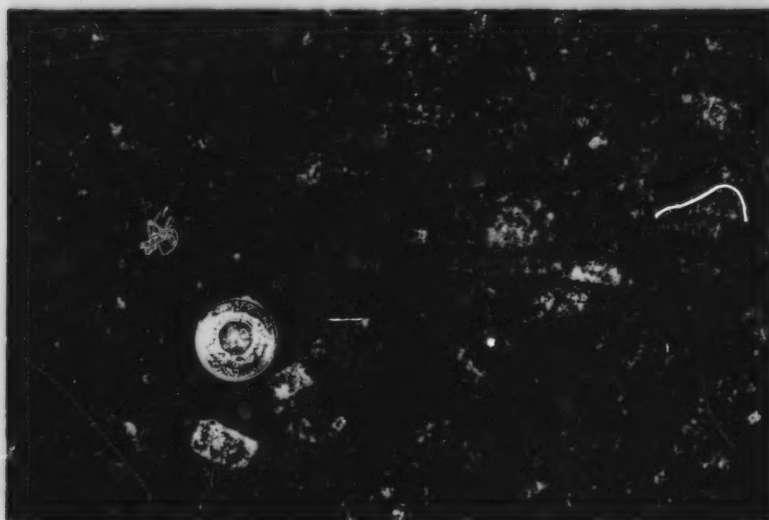


Figure GS-14-12: Megacrystic hornblende monzogranite likely related to the Chipewyan Batholith, western shoreline of Strawberry Island, Southern Indian Lake; note the excellent preservation of igneous textures, including zoning in feldspar; coin is 2.5 cm across.

In the Reindeer Lake area, three main tectonothermal phases were recognized:

- Pre-Wathaman, orogen-parallel, large-scale recumbent folds (F_1) related to terrane accretion onto the Hearne craton margin (D_1-M_1);
- South-vergent thrusting and thrust-stacking associated with 1825 to 1800 Ma terminal collision, which produced tight to isoclinal, nearly coaxial, syn-peak metamorphic, F_2 folds and high-strain zones (D_2-M_2); and
- Late-tectonic, upright, open crossfolds (F_3) produced during a late-orogenic D_3 event that may locally be associated with retrograde metamorphism (D_3-M_3 ; Corrigan et al., 1999b).

Along the Churchill River–Southern Indian Lake transect, evidence for D_1-M_1 and D_2-M_2 is widespread, but late-orogenic D_3 folds are either poorly developed or simply absent. Although these are the only three 'events' that can be correlated at a regional or 'tectonic' scale, more detailed studies have revealed further complexities (i.e., Beaumont-Smith and Rogge, 1999) that may reflect local boundary conditions during the accretionary and collisional phases of the orogen.

ECONOMIC POTENTIAL

The Lynn Lake and Rusty Lake belts host numerous economic gold and volcanogenic massive-sulphide deposits, and undoubtedly have the potential to contain yet more undiscovered ore. However, potential also exists for other types of ore deposits, such as gold deposits near the reworked margins of large plutons, a common feature in the La Ronge Belt in Saskatchewan (Lafrance, 1999). Our preliminary work in the Rusty Lake belt has shown that there may be a potential for similar deposits in the marginal zones of plutons, near contacts with supracrustal rocks. Other units of interest include gabbro-monzodiorite with disseminated sulphides in the Pukatawakan Bay area and layered mafic-ultramafic-intermediate intrusions in the Turtle Island area. The gabbro-monzodiorite intrusion between Pukatawakan Bay and Whyne Bay (see

'Pukatawakan Bay' section) is poorly exposed, but one small outcrop on the shore of Southern Indian Lake contained 1 to 2% disseminated sulphide minerals that locally form clots up to 5 mm in diameter containing approximately equal proportions of chalcopyrite and another sulphide, possibly pyrite. Assay results were not yet available at the time of publication. The mafic-ultramafic-intermediate layered intrusion on the north shore of Turtle Island contains only a small proportion of ultramafic rock and only minor sulphides. However, it shows evidence of multiple injections in a dynamic, mafic magma system, a feature considered significant in exploration for platinum-group elements.

Only a relatively minor amount of sulphide minerals was observed in association with the Pukatawakan Bay and Partridge Breast belt volcanic assemblages. However, only small portions of the belts were exposed in the areas visited, so potential may exist in unexposed segments. Carbonate and silicate alteration does appear to be pervasive, suggesting that fluids were present, as does the local alteration of metagabbro to a garnet-cummingtonite assemblage. One other notable observation was the presence of a number of tourmaline- and locally beryl-bearing pegmatite dykes emplaced in supracrustal rocks of the Partridge Breast belt along the banks of the lower Churchill River between Southern Indian Lake and Partridge Breast Lake. These may present potential targets for rare-earth elements.

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SUMMARY

Rock, till, b-horizon soil, humus and vegetation samples were collected during the month of July for multi-element geochemical analysis from 157 sites in the area west, north and east of the northern half of the Knee Lake greenstone belt. The sampling included 150 bulk samples of till and beach sand (20–25 kg) collected for kimberlite indicator-mineral identification and analysis. Samples are currently undergoing preparation for geochemical analysis in the laboratories of the Manitoba Geological Survey.

2001 SURVEY

Helicopter- and fixed-wing-assisted, belt-scale (1 km sample spacing), multimedia geochemical and mineralogical surveys in northeastern Manitoba were concentrated in the northern portion of the Knee Lake greenstone belt, including the belt that trends eastward to Fish Lake (Fig.GS-15-1). The distribution of sampling sites for the 2001 survey is given in Figure GS-15-2. Sample collection in 2001 was accomplished entirely by helicopter by two separate sampling crews. This year's sampling was designed to:

- extend or truncate the kimberlite indicator-mineral (KIM) dispersion train defined in 1999 and 2000 in the Knee Lake greenstone belt (Fedikow et al., 2000, 2001a, 2001b);
- define the eastern limits of the 1999 and 2000 Knee Lake KIM dispersion train;

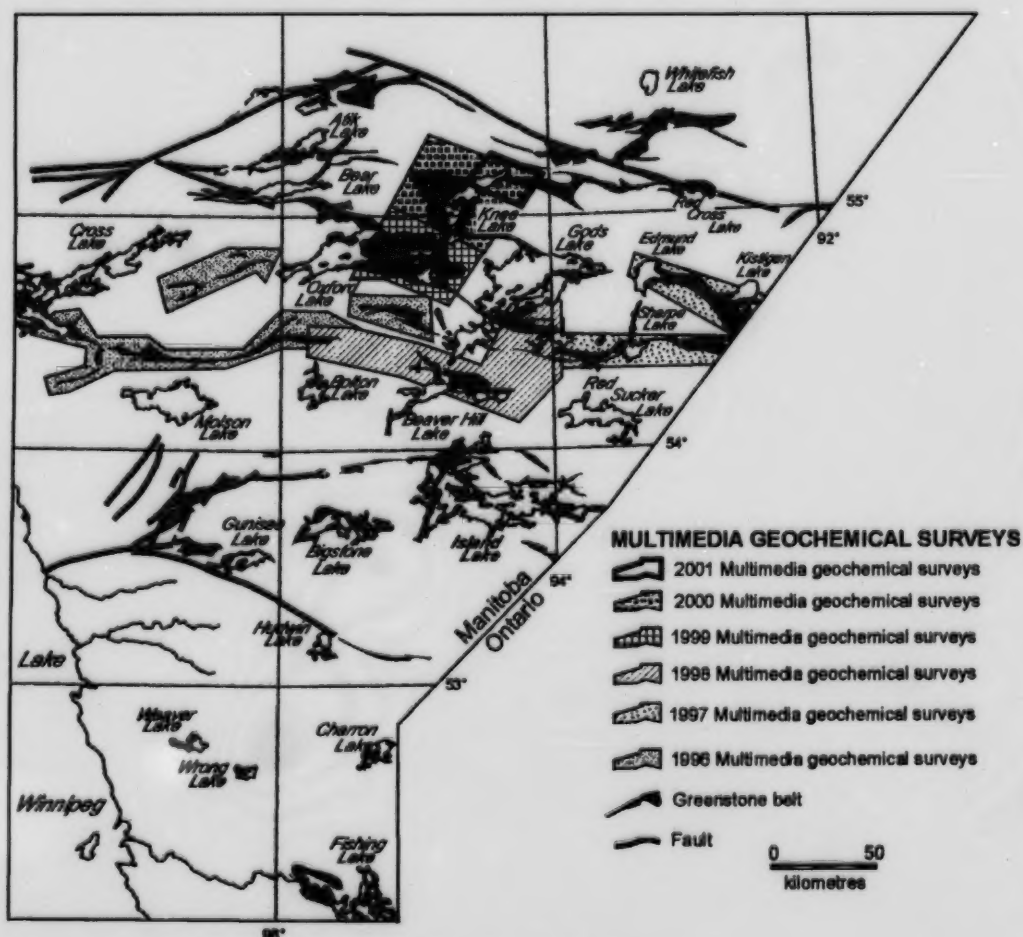


Figure GS-15-1: Target areas for multimedia geochemical surveys, 1996-2001

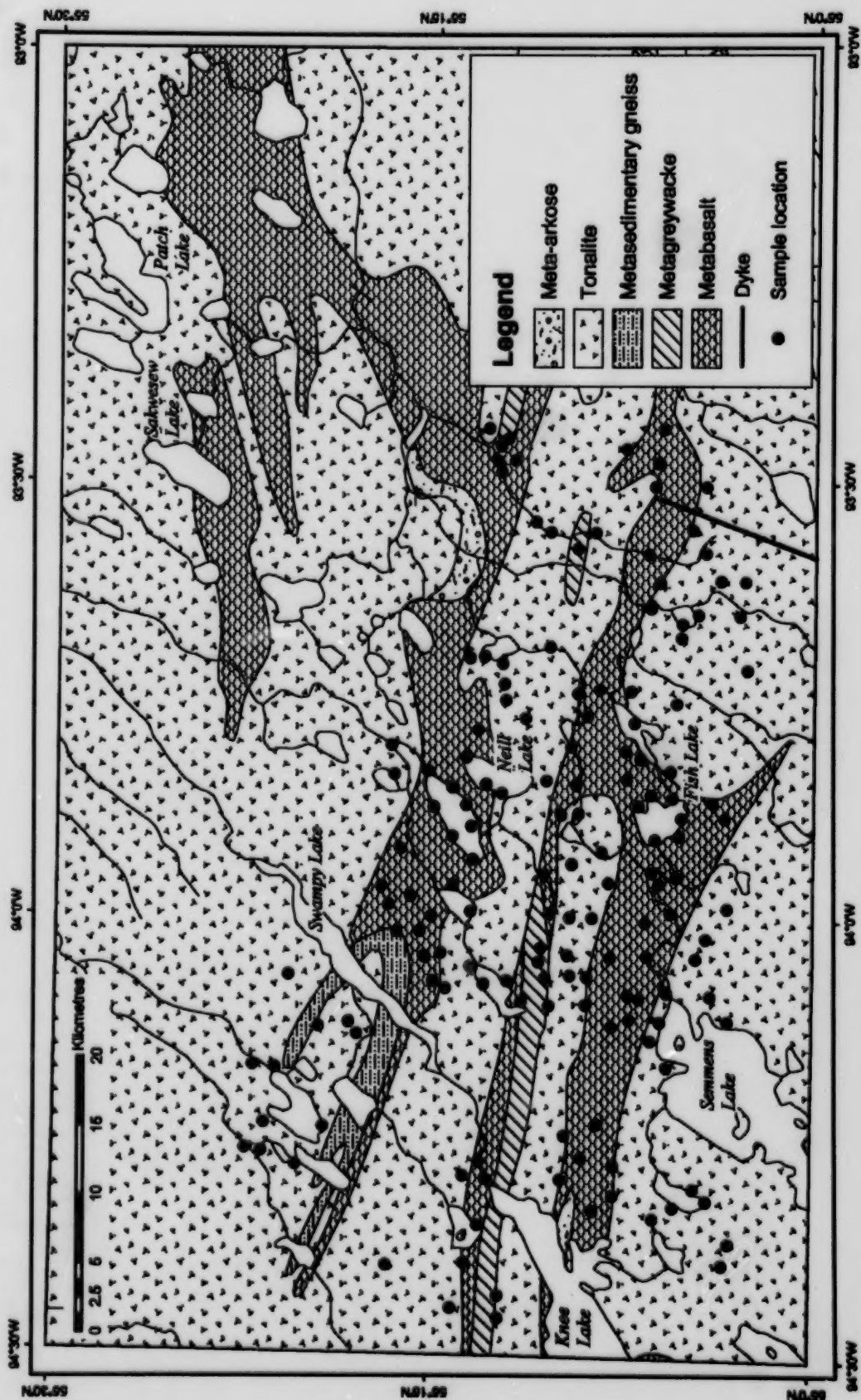


Figure GS-15-2: Distribution of sampling sites for the 2001 survey area.

- assess the possibility that multimedia geochemical analyses have effectively mapped out the Knee Lake KIM dispersion train, with the possibility that the analysis of any one of these media may represent an alternative to bulk till sampling for diamond exploration; and
- assess the greenstone belt that extends east from the northern end of Knee Lake to Fish Lake for base-metal, precious-metal and diamond potential.

The geochemical and mineralogical analysis of these samples will continue to build a multi-element-multimedia geochemical database initiated under the Operation Superior program between 1996 and 2000 (Fedikow et al., 1996, 1997a, 1997b, 1998, 1999, 2000, 2001a, 2001b; Fedikow et al., work in progress, 2001; Fedikow and Nielsen, 1997, 1998, 1999, 2000) to assist mineral-resource assessment in the northern Superior Province of Manitoba.

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SUMMARY

On the basis of previous mapping and work on geochronology and metamorphism, we have conducted structural analysis of the central and southern parts of the Cross Lake greenstone belt, concentrating on the east-southeast-trending high-strain zone. Five generations of deformation have been identified. The D_1/D_2 deformation is defined by isoclinal folds, which are intrafolial to a dominant transposition foliation. Folds belonging to D_3 are generally open to tight asymmetrical and overprint the transposition foliation. Both D_1/D_2 and D_3 have a dextral sense of movement, and are interpreted as a continuous progressive deformation. The D_4 deformation is defined by en échelon veins observed in amphibolite or other more competent layers. The veins indicate a sinistral sense of movement. Folds associated with D_4 are difficult to recognize. The D_5 deformation produces open asymmetrical folds that indicate a dextral sense of movement. Dextral transposition associated with D_1/D_2 is responsible for the transposition and the formation of the shear zone.

INTRODUCTION

The Cross Lake greenstone belt is near the western edge of the Gods Lake Domain and extends westward into the Pikwitonei (granulite) Domain in the Superior Province of Manitoba. The belt has two sets of shear zones, one trending east-southeast and the other trending northeast. Previous work in this area on detailed stratigraphy, geochronology and metamorphic history includes Corkery (1983, 1985), Corkery et al. (1988), Corkery and Lenton (1989) and Corkery et al. (1992). A thermotectonic pilot study of the Cross Lake greenstone belt was conducted by Breedveld (1989).

Corkery et al. (1992) described three distinct unconformable groups of supracrustal rocks that make up the Cross Lake greenstone belt:

- 1) the Pipestone Lake Group (2760 Ma), a sequence of metavolcanic and subordinate metasedimentary rocks, weakly to strongly deformed pillowed basalt and minor massive basaltic flows;
- 2) the Gunpoint Group (2730 Ma), a fining-upward clastic sedimentary sequence with interbedded felsic volcanic rocks that unconformably overlies the older Pipestone Lake Group; and
- 3) the Cross Lake Group (<2710 Ma), a fining-upward sequence of fluvial-marine clastic sedimentary rocks with shoshonitic volcanic rocks near the top, unconformably overlying the Gunpoint Group.

The metamorphic grade of the Cross Lake greenstone belt increases from upper greenschist facies at Pipestone Lake to hypersthene granulite grade in the gneissic terrane northwest of Cross Lake (Breedveld, 1988).

The structural framework and kinematic evolution of the belt are unclear. Understanding the deformation history of the two sets of shear zones is critical and will elucidate the regional tectonics of the northwestern Superior Province. We carried out a structural analysis on a major east-southeast-trending shear-zone area, the central Cross Lake Shear Zone (CCLSZ), during the summer of 2001 with support from the University of Maryland and from Manitoba Industry, Trade and Mines. The study area starts at a point west of Pipestone Lake and extends about 15 km westward along central Cross Lake, between Cross Island in the north and Ross Island in the south (Fig. GS-16-1). Large-scale mapping was carried out within and adjacent to the CCLSZ and preliminary results of the fieldwork are reported below.

PRELIMINARY RESULTS OF STRUCTURAL ANALYSIS

Five generations of deformation are distinguished on the basis of style, overprinting relationships and sense of movement.

Deformations D_1 and D_2

The earliest deformation structures recognized in the CCLSZ are F_1 and F_2 isoclinal and commonly asymmetrical folds, which are intrafolial to a dominant east-southeast-trending transposition layering (S_T) that occurs throughout the zone. The two generations are indistinguishable, unless observed where a rare overprinting relationship occurs. Axes of the F_1/F_2 folds plunge moderately to steeply northeast (Fig. GS-16-2). Some F_1/F_2 folds have sheath fold geometry. An east-northeast-trending foliation (S_1/S_2) is defined by the preferred orientation of minerals and a local compositional layering. This S_1/S_2 foliation generally overprints the isoclinal folds intrafolial to S_T , but is axial planar to some. The geometrical relationship

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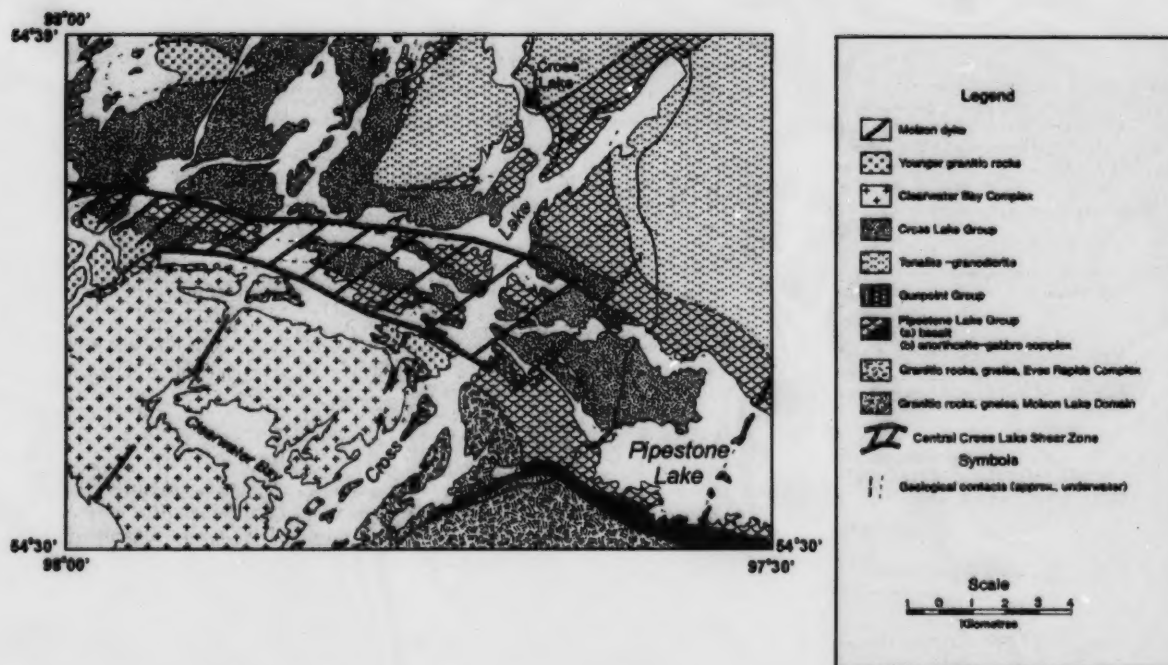


Figure GS-16-1: Simplified geology of the central Cross Lake greenstone belt (modified from Corkery et al., 1992).

between S_1/S_2 and S_T is constant, where not obscured by later deformation. The S_T transposition layering is inclined to S_1/S_2 by about 10 to 20° (Fig. GS-16-2). Treating it as an S/C fabric (S_T/C and $S_1/S_2/S$ fabric), a dextral sense of shear of D_1/D_2 deformation is indicated. The L_1/L_2 lineations, which are defined by F_1/F_2 axes, aligned hornblende and the intersection between S_1/S_2 and S_T , plunge moderately to steeply northeast.

Boudinage is a common feature of the S_T fabric at scales varying from millimetres to metres. In some layers (e.g., pegmatite, amphibolite), the separation of boudins can be greater than their long dimension as seen on outcrop. Other layers may show considerable continuity. Boudins are generally on the limbs of F_1/F_2 folds, which indicates that they may be contemporary with folding. Boudin neck folds occur commonly, and are usually asymmetrical. The consistent Z style also indicates a dextral sense of shear that is consistent with the D_1/D_2 deformation. However, this asymmetry could also be due to D_3 modification (see below).

Pegmatite dykes subparallel to S_T are another common feature of D_1/D_2 . Pegmatite layers are locally cut and dragged (Lister and Williams, 1983) by S_T , and the sense of shear is dextral. These pegmatites are isoclinally folded (Fig. GS-16-3) and commonly boudinaged. Some pegmatites related to D_1/D_2 are overprinted by later stages of deformation (e.g., D_3).

Deformation D_3

The F_3 folds are generally open to tight drag folds, and commonly have a Z geometry. They fold the transposition foliation S_T and S_1/S_2 . There is a weak axial-plane foliation (S_3) defined by shape fabrics. Axes of F_3 folds plunge steeply. Shear-sense indicators (e.g., asymmetrical boudinage) indicate dextral sense of movement. The D_3 deformation overprints D_1/D_2 transposed pegmatite dykes with open to tight drag folds (Fig. GS-16-4a, b). There is a gradation in the tightness of F_3 folds. Some very tight F_3 folds with an axial-plane foliation are distinguishable from F_1/F_2 folds only by virtue of their association with more open F_3 folds. The kinematics from D_1/D_2 to D_3 are consistently dextral. We interpret this as progressive deformation.

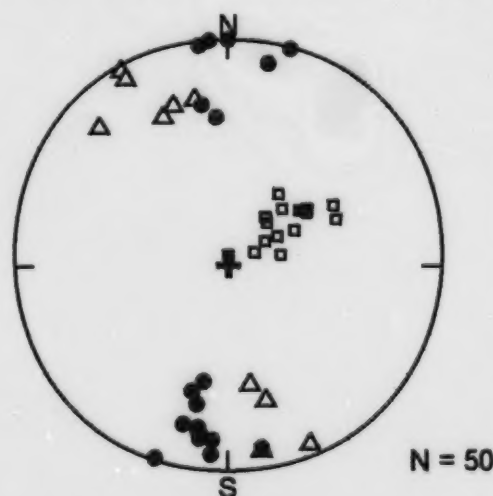


Figure GS-16-2: Lower hemisphere equal-area plot of F_1-F_2 fold axes (square), S_T (dot) and S_1-S_2 foliation (triangle).

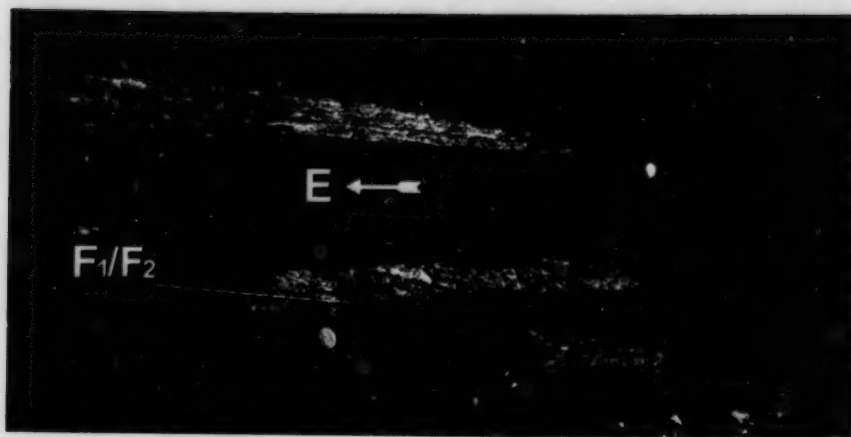


Figure GS-16-3: Isoclinal F_1/F_2 fold in pegmatite dykes in Cross Lake Group sandstone, northern Ross Island.

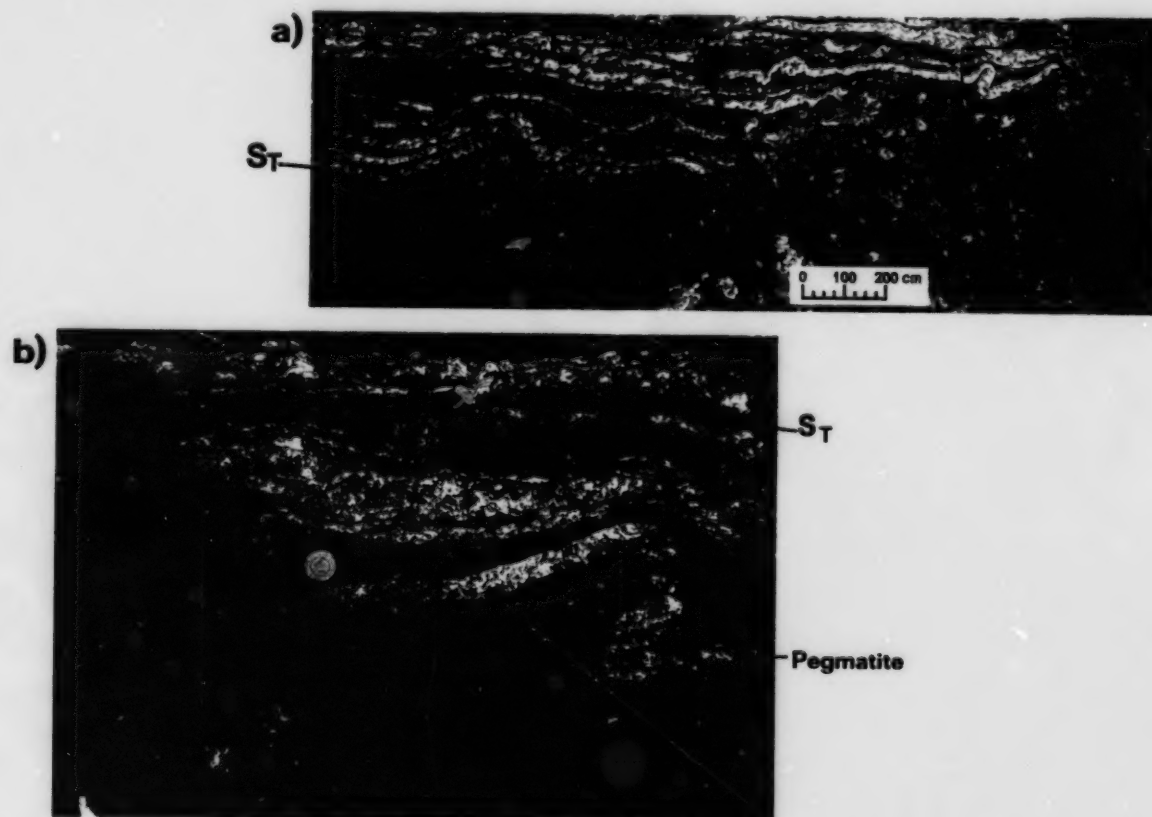


Figure GS-16-4: a) Open to tight F_3 drag folds of pegmatite dykes in Cross Lake Group sandstone; b) late and medium stage of F_3 folding, southwestern Cross Island; note coin for scale.

Deformation D_4

Normal to sigmoid, en échelon pegmatite and quartz veins occur commonly in amphibolite layers parallel to S_T . They consistently indicate a sinistral sense of movement. The development of en échelon structure is also an indication that the deformation condition is near the brittle-ductile transition. This and the sense of shear are in contrast to the sense of shear from D_1/D_2 to D_3 .

It is difficult to distinguish F_4 folds from F_3 folds. Open to tight S-folds in the CCLSZ overprint S_T , with axes plunging shallowly to steeply. In some outcrops, S-folds are clearly smaller scale parasitic F_3 folds whose larger scale geometry is Z shaped. We interpret continuous chains of S-folds as F_4 folds, but realize that some of them may belong to F_3 . Where isolated S-folds are observed, it is impossible to tell whether they are F_3 or F_4 . Metamorphism associated with some of these folds is being investigated in the hope that it may help identify these folds.

Deformation D₅

The F₅ folds are mostly asymmetrical and commonly open, and the fold axes plunge steeply. The sense of movement of this generation is dextral. The F₅ folds overprint D₄ structures; for example, D₄ sinistral en échelon veins containing layers are overprinted by F₅ Z-folds (Fig. GS-16-5). The F₅ Z-folds can only be distinguished from F₃ Z-folds where the overprinting relationship between F₅ and D₄ is observed. The Z-shape asymmetry of D₁/D₂ boudin neck folds may have been further enhanced by D₅ dextral shear.

DISCUSSION

Based on the observations outlined above, we conclude that the CCLSZ is primarily a D₁/D₂ structure. The F₃, F₄ and F₅ folds can be interpreted as drag folds (Jiang and Williams, 1999), developed largely due to transposition-foliation-parallel shear. The D₁/D₂ deformation is transpression shear, which makes it difficult to interpret the origin of F₁/F₂ folds. From our structural analysis of folds outside the shear zone, we think that F₁/F₂ folds originated before shearing (i.e., they were inherited from pre-D₁/D₂ deformation). The D₁/D₂ transpression shear strongly modified their geometries and led to complete transposition of bedding. The D₃ deformation is likely the progression of D₁/D₂. The reversal in sense of shear during D₄ is responsible for producing the conflicting sense of structures observed in the CCLSZ. The deformation became dextral again during D₅. The CCLSZ thus has a complicated kinematic history. Preliminary mapping in the northeast-trending high-strain zones to the north of the CCLSZ also suggests similar polyphase deformation. We suggest that the two sets of shear zones may have a conjugate kinematic relationship.

ACKNOWLEDGMENTS

The project is supported by University of Maryland and Manitoba Industry, Trade and Mines. We would like to express our gratitude to Paul F. Williams, Shoufa Lin, Chris Beaumont-Smith and Andy Parmenter for discussion, Neill Brandon for his support, and Jerine Thatcher for her tireless field assistance.

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Figure GS-16-5: Sinistral en échelon D₄ structure overprinted by F₅ fold in Cross Lake Group sandstone, southern Metis Island.

**GS-17 GEOLOGY AND GEOCHRONOLOGY OF THE ISLAND LAKE GREENSTONE BELT,
NORTHWESTERN SUPERIOR PROVINCE**

by J. Parks¹, S. Lin¹, M.T. Corkery and D.W. Davis²

Parks, J., Lin, S., Corkery, M.T. and Davis, D.W. 2001: Geology and geochronology of the Island Lake greenstone belt, northwestern Superior Province; in Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 115-120.



SUMMARY

The Island Lake greenstone belt is composed of volcanic and volcanogenic sedimentary rocks of the Hayes River Group and sedimentary rocks of the Island Lake Group, all of which are intruded by various plutons. Field mapping and geochronological work in 2001 demonstrated that 1) the Hayes River Group in the western portion of the belt can be divided into lithologically and chronologically distinct structural panels that are correlated with those previously defined in the eastern portion of the belt; 2) there exists a distinct ca. 2728 Ma volcanic unit in the belt; and 3) the Island Lake Group is unconformable on the Bella Lake pluton. The mapping also led to a better definition of the location and nature of the Savage Island Shear Zone in the western part of the belt and the kinematics of the Chapin Bay Shear Zone in the area.

INTRODUCTION

The Island Lake greenstone belt is one of the largest greenstone belts in the northwestern Superior Province. The purpose of this study is to improve the understanding of the depositional, structural and tectonic evolution of this greenstone belt. To this end, an eight-week field-mapping and sampling program was conducted during the summer of 2001, following a one-week field-sampling program in 2000. Seven samples collected in 2000 have been dated at the Jack Satterly Laboratory of the Royal Ontario Museum. Preliminary results of these studies are summarized in this paper.

The Island Lake greenstone belt was mapped at a scale of 1:63 360 by Godard (1963a, 1963b), and at a scale of 1:20 000 by Neale (1981), Neale and Weber (1981), McGregor and Weber (1982), Neale et al. (1982), Weber et al. (1982a, 1982b), Gilbert et al. (1982, 1983) and Gilbert (1984, 1985a, 1985b). An isotope study was carried out by Stevenson and Turek (1992), and U-Pb geochronology studies were done by Turek et al. (1986) and Corfu and Lin (2000). The geology of mineral occurrences has been described by Theyer (1998), Lin and Cameron (1997), and Lin and Corfu (in press). The current study is, in part, a continuation of work started by Lin et al. (1998) and Corfu and Lin (2000).

GENERAL GEOLOGY

The Island Lake greenstone belt is composed of volcanic and volcanogenic sedimentary rocks mapped as the Hayes River Group (HRG; Weber et al., 1982b) and the younger sedimentary rocks of the Island Lake Group (ILG), all of which are intruded by various plutons. The ca. 2744 Ma Bella Lake pluton (Corfu and Lin, 2000) occupies the central portion of the area and divides the belt into eastern and western portions (Fig. GS-17-1). Lin et al. (1998) were mostly concerned with the eastern portion, whereas the present mapping is focussed on the western portion, particularly the Cochrane Bay area.

Structural Panels and the Hayes River Group (HRG)

The term Hayes River 'Group' has traditionally been applied to all volcanic and volcanogenic sedimentary rocks in this greenstone belt. However, the geochronology of Corfu and Lin (2000) and new preliminary data presented in this report indicate that the Hayes River 'Group' in fact includes supracrustal rocks of three different ages, and that these chronologically different rocks occur in different structural panels (Lin et al., 1998; this study). It is clear that use of the term Hayes River 'Group' must be re-evaluated for all of the volcanic rocks in this greenstone belt. Nevertheless, no new subdivision has been made, and the term Hayes River Group (or HRG) is used in this report for all supracrustal rocks older than the ILG.

Lin et al. (1998) have divided the eastern portion of the belt into four lithologically, chronologically and geochemically distinct structural panels, separated by the Whiteway Channel Shear Zone, the Harper Island Shear Zone and the Savage Island Shear Zone (Fig. GS-17-1). The panel south of the Savage Island Shear Zone (panel I) contains metamorphosed mafic, intermediate and felsic volcanic and volcanogenic sedimentary rocks. Two dacite samples from this panel yielded identical zircon ages of ca. 2852 Ma (Corfu and Lin, 2000), and detrital zircons from a sedimentary rock yielded ages between ca. 2858 and ca. 2847 Ma (Corfu and Lin, 2000). The HRG in the panel between the Savage Island and Harper Island shear zones (panel II) consists mainly of pillowed basalt and related mafic and ultramafic intrusive rocks. A quartz-phyric felsic tuff was discovered in this panel in 2001 and will be dated to directly constrain the age of the panel. The panel between the Harper Island and Whiteway Channel shear zones (panel III) consists of pillow basalt and minor volcanogenic sedimentary rocks. A gabbroic intrusion in this panel yielded a zircon age of 2807 ± 1 Ma (Corfu and Lin, 2000), and all three detrital zircon grains

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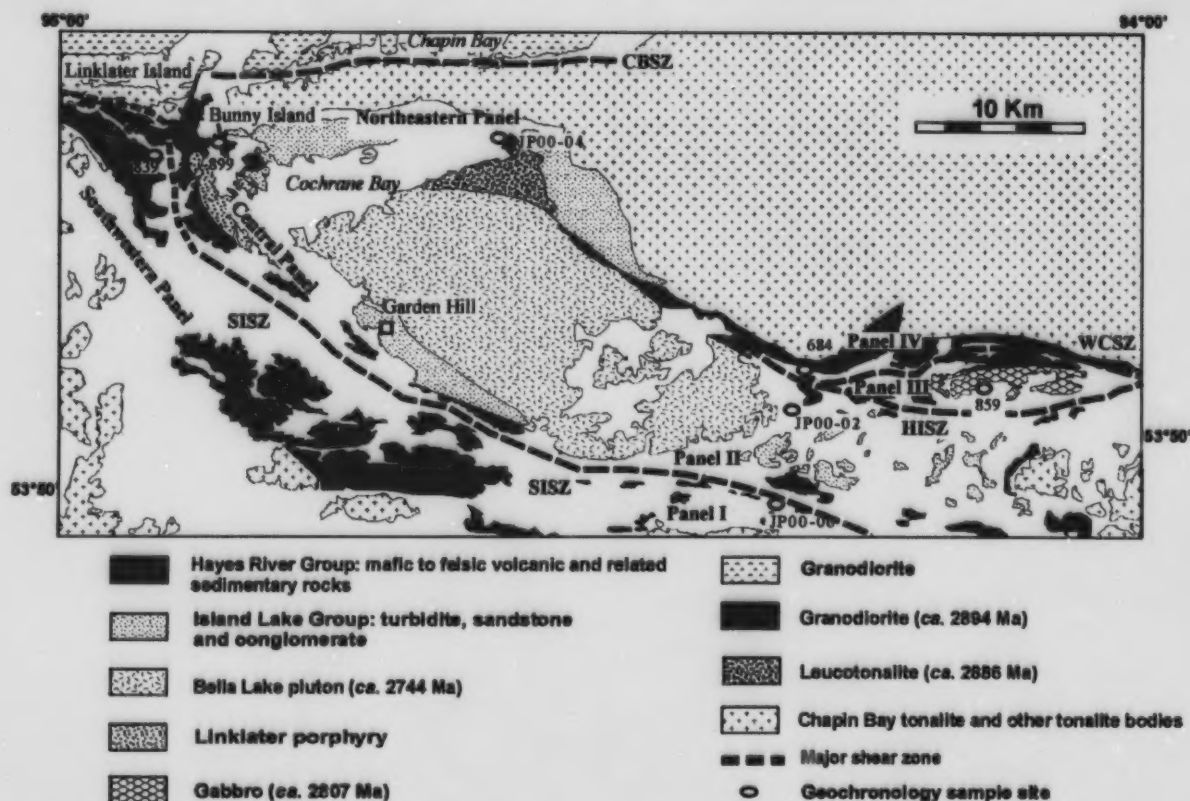


Figure GS-17-1: Simplified geology of the Island Lake greenstone belt.

dated so far from a sedimentary rock yielded essentially identical ages of ca. 2897 Ma (sample 859, this study). The panel north of the Whiteway Channel Shear Zone (panel IV) consists of amphibolite-grade mafic and ultramafic volcanic rocks. No material suitable for U-Pb dating has been found in this panel.

In the western portion of the belt, mapping in 2001 has led to the recognition of three lithologically and chronologically distinct structural panels: the southwestern, central and northeastern panels (Fig. GS-17-1). The southwestern panel occurs to the southwest of the Savage Island Shear Zone, contains pillowed and massive basalt, felsic volcanic rocks and volcanogenic sedimentary rocks, and can be traced unambiguously into panel I in the eastern portion of the belt. A dacite sample from the southwestern panel, collected west of Linklater Island, has yielded a zircon age of 2852 ± 1 Ma (sample 839, this study). The northeastern panel is exposed in the eastern part of Cochrane Bay and consists of sedimentary rocks, an older leucotonalite unit and an older granodiorite unit. The leucotonalite has a zircon age of 2886 ± 15 Ma (Turek et al., 1986), and the granodiorite has a zircon age of 2894 ± 1 Ma (sample JP00-04, this study). We tentatively correlate this panel with panel III in the eastern portion of the greenstone belt, based on similar zircon ages and the fact that the two panels are approximately along strike.

The central panel occurs in the Bunny Island area (Fig. GS-17-1) and contains pillowed and massive basalt, and related felsic volcanic rocks and subvolcanic porphyry. The felsic volcanic rock yielded a zircon age of ca. 2728 Ma (sample 899, this study). This panel is thus distinctly younger than the southwestern panel (or panel I in the east). Field mapping shows that this panel has sheared contacts with the Linklater porphyry and the Island Lake Group (Fig. GS-17-1). We suspect that this panel can be correlated with panel II in the east, based on similar lithological association and similar location relative to other panels. Additional geochronological and geochemical work (especially geochronological work on the newly discovered felsic tuff in panel II) will help to test this correlation.

Island Lake Group (ILG)

The Island Lake Group (ILG) unconformably overlies the Hayes River Group and is composed of conglomerate, sandstone and turbidite sequences. Detrital zircon work by Corfu and Lin (2000) on two wacke samples from the upper part of the sequence shows that this part of the sequence is younger than ca. 2712 Ma. However, the lower part of the sequence was believed to be intruded by the ca. 2744 Ma Bella Lake Pluton (Lin et al., 1998; Corfu and Lin, 2000); if correct, this indicates

that the ILG was deposited over an extended period of time. During the summer of 2001, a critical outcrop was cleaned and re-examined. The results called the intrusive relationship into serious doubt and instead indicate an unconformable relationship between the ILG and the pluton (Fig. GS-17-2). To test this important relationship, a wacke sample was collected near the contact at this outcrop for detrital zircon analysis. The youngest zircon dated so far has an age of ca. 2717 Ma (sample JP00-02, this study), younger than the Bella Lake pluton and thus supporting the unconformable relationship. The ILG is intruded by a ca. 2699 Ma porphyry (the Horseshoe Island porphyry in the Cochrane Bay area; Turek et al., 1986). The age of sedimentation of the ILG is thus constrained between ca. 2712 Ma and ca. 2699 Ma.

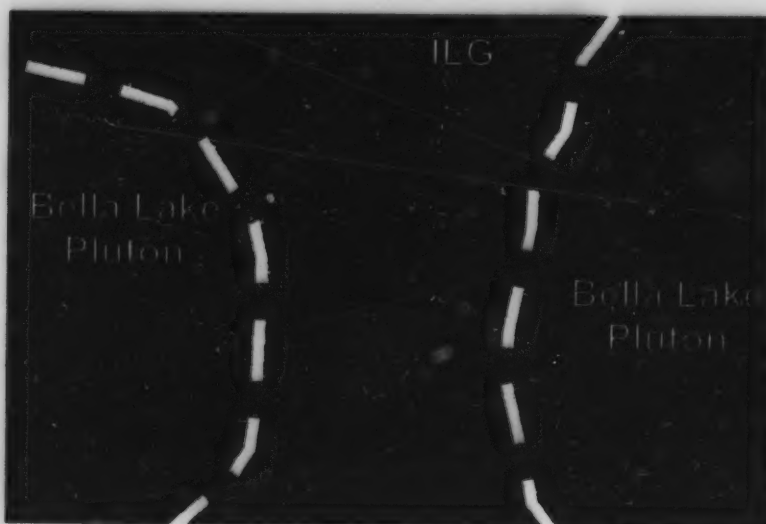


Figure GS-17-2: Unconformable relationship between the Bella Lake pluton and the Island Lake Group in the eastern part of the map area. The Island Lake Group infills a scour in the Bella Lake pluton.

STRUCTURE

The Island Lake greenstone belt has undergone multiple generations of deformation that have produced at least four distinct shear zones: the Whiteway Channel, Harper Island, Savage Island and Chapin Bay shear zones (Fig. GS-17-1). The structure in the eastern portion of the belt was described by Lin et al. (1998). Here we are mainly concerned with the structure in the western portion.

Savage Island Shear Zone (Western Segment)

The Savage Island Shear Zone is a major shear zone that trends east-southeast to southeast across the map area. It was previously well defined in the east (Lin et al., 1998) and mapping in the summer of 2001 helped to better define it in the west. It was traced with confidence from southeast of the town of Garden Hill to southwest of Linklater Island, and separates the ca. 2852 Ma southern panel from the ca. 2728 Ma central panel (Fig. GS-17-1). In this area, both a sedimentary unit (most likely of Hayes River Group) and a gabbroic unit are sheared (Fig. GS-17-3). The foliation in the shear zone strikes west-northwest and dips moderately to steeply southwest. The lineation plunges moderately to the southeast. South of the town of Garden Hill, a late crenulation transposes an early northwest-trending foliation into a west-trending, steeply dipping foliation. Shear-sense indicators (boudinaged quartz veins and rotated porphyroclasts) show both sinistral and dextral movement, suggesting that the shear zone has a complicated deformation history.

Chapin Bay Shear Zone

Field mapping shows an extensive (approx. 1 km wide and at least 30 km long) shear zone, the Chapin Bay Shear Zone, that trends east-west along the northern edge of the western portion of the map area. This shear zone strongly deforms the Chapin Bay tonalite, a granodiorite unit north of the Chapin Bay tonalite and a small (approx. 5 km by 300 m) sediment sliver, consisting mainly of conglomeratic rocks, situated between these two units (Fig. GS-17-4). Foliation in the shear zone strikes west and dips steeply to the north to vertically. Lineation varies from plunging shallowly (approx. 30°) east in the margins of the shear zone to plunging moderately (approx. 60–80°) east in the centre of the shear zone. Field observations indicate a sinistral strike-slip component and north-over-south dip-slip component along the shear zone. An S/C fabric and rotated plagioclase porphyroclasts are well developed in a deformed tonalite in the shear zone and indicate sinistral shearing (Fig. GS-17-5).

Timing of Deformation Events

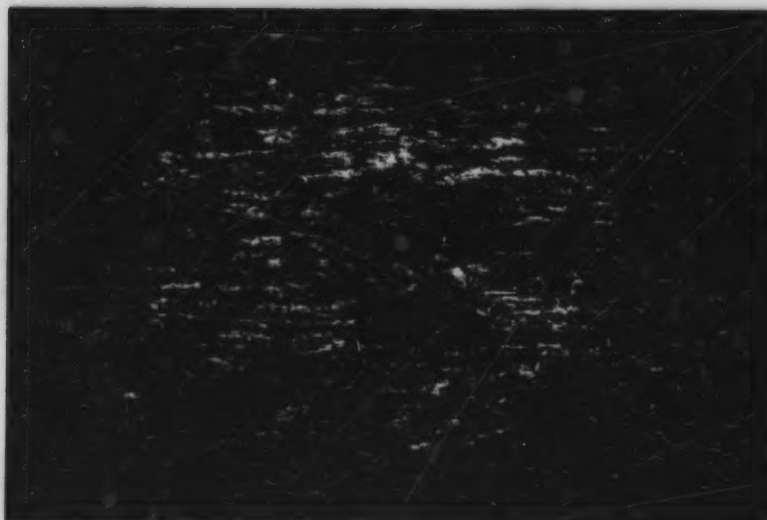
A major objective of this project is to place geochronological constraints on the timing of deformation in this greenstone

Figure GS-17-3: Foliated gabbro in the Savage Island Shear Zone. Foliation in gabbro is parallel to the dashed line in the photo.



Figure GS-17-4: Strongly deformed conglomerate unit in the Chapin Bay Shear Zone. This unit can be traced laterally into areas where the clasts are rounded and less deformed.

Figure GS-17-5: Sheared porphyroclasts and mylonitic texture of the Chapin Bay Shear Zone in the Chapin Bay tonalite. Asymmetric tails indicate sinistral movement.



belt. So far, two dykes from the eastern portion of the greenstone belt have been successfully dated for this purpose. In the Harper Island Shear Zone, an approximately 15 m wide late syntectonic tonalite dyke has yielded a zircon age of 2722 ± 1.2 Ma (sample 684, this study). The dyke is weakly foliated and contains xenoliths of more strongly foliated mafic volcanic rocks. South of the Savage Island Shear Zone in panel I, a postkinematic quartz-porphyry dyke yielded a preliminary zircon age of 2723 ± 1.8 Ma (sample JP00-06, this study). The latter dyke is unfoliated and cuts a strong foliation in deformed mafic volcanic rocks (Fig. GS-17-6). Detailed work by Lin et al. (1998) showed that this foliation predates the Savage Island Shear Zone.



Figure GS-17-6: Coarse-grained felsic dyke cutting foliation in strongly deformed mafic volcanic rocks.

CONCLUSIONS AND FUTURE WORK

The Hayes River Group within the Island Lake greenstone belt can be divided into lithologically and geochronologically distinct structural panels that can be correlated across the entire belt. The central panel in the west consists of distinct volcanic rocks that are ca. 2728 Ma in age, much younger than other dated rocks of the Hayes River Group. The use of the term Hayes River Group for all volcanic and volcanogenic rocks in this greenstone belt needs to be re-evaluated. The Island Lake Group is confirmed to have an unconformable contact with the Bella Lake pluton.

The western segment of the Savage Island Shear Zone is kinematically complicated and shows evidence for both dextral and sinistral shearing. The Chapin Bay Shear Zone is an extensive structure along the northern edge of the western part of the map area and has experienced strong deformation with a sinistral strike-slip component and a north-over-south dip-slip component.

To further constrain the geological evolution of the Island Lake greenstone belt, additional U-Pb analyses will be done at the Jack Satterly Laboratory of the Royal Ontario Museum. Geochemical analyses, including Sm-Nd work, are also planned to help characterize the different panels and test the correlation of the panels from east to west. Detailed microstructural work will be conducted on samples taken this summer. In particular, work will be done to determine the sequence of movements on the western segment of the Savage Island Shear Zone and to confirm the sense of shear along the Chapin Bay Shear Zone.

ACKNOWLEDGMENTS

Funding for this project has been generously supplied by the Manitoba Geological Survey, LITHOPROBE, the Northern Scientific Training Program and the University of Waterloo. Geochronology analyses were done at the Jack Satterly Laboratory of the Royal Ontario Museum (ROM). J. Parks would like to thank H. Zwanzig for reviewing this manuscript, the staff at the ROM for their help, Scott Snider for his invaluable field assistance, Neill Brandson for logistical support, and many friends at Island Lake for their hospitality over the summer.

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Nielsen, E. 2001: Quaternary stratigraphy, till provenance and kimberlite indicator-mineral surveys along the Lower Hayes River; in Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 121-125.

SUMMARY

During the past field season, 69 till and two alluvial sand samples were collected from seven sections exposed in river cuts in the northern Superior Province and adjacent Hudson Bay Lowland of Manitoba. The survey was undertaken to outline the Quaternary stratigraphy and determine the provenance of tills in the northern Superior Province and adjacent Hudson Bay Lowland of Manitoba in support of diamond exploration. These objectives will be met using a combination of pebble analysis, carbonate analysis, matrix geochemistry, textural analysis, kimberlite indicator-mineral analysis and pebble-fabric analysis.

INTRODUCTION

The Manitoba Geological Survey has undertaken multimedia geochemical and kimberlite indicator-mineral surveys across the northern Superior Province over the past six years. These surveys have attracted the attention of numerous major and minor mineral exploration companies (Fedikow et al., 1997, 1998, 1999, 2000). While interest in kimberlite indicator minerals has been particularly high, the source(s) of the indicators continues to elude investigators. Manitoba Geological Survey's kimberlite indicator-mineral surveys, as well as most of those sponsored by the mineral exploration industry, have been conducted in areas of relatively thin till and samples have generally been collected from hand-dug pits. However, sampling from hand-dug pits is not a viable technique for mineral-tracing surveys in the Hudson Bay Lowland and adjacent areas of the northern Superior Province because the overburden may be more than 100 m thick and multiple tills of uncertain provenance subcrop at depth. Prior to extending mineral-tracing and geochemical surveys into the northernmost part of the northern Superior Province and adjacent Hudson Bay Lowland, reverse circulation drilling or other 'remote' sampling would be necessary to gain a clear understanding of the subsurface stratigraphy and till provenance. Mapping of selected river exposures would greatly enhance the understanding of the Quaternary stratigraphy and till provenance in support of regional mineral exploration, especially for diamonds.

OBJECTIVES

This survey was undertaken to outline the Quaternary stratigraphy and determine the provenance of tills in the northern Superior Province and adjacent Hudson Bay Lowland of Manitoba in support of regional mineral exploration. These objectives will be met using a combination of pebble analysis, carbonate analysis, matrix geochemistry, textural analysis, kimberlite indicator-mineral analysis and pebble-fabric analysis.

RELIEF

Most of the area south of Hudson Bay and east of the Nelson River has low relief. The study area includes areas underlain by Paleozoic carbonate bedrock and the Fox River greenstone belt, and the area south to the latitude of Brassey Hill (approximately 55° 30' N). Thick overburden, permafrost and extensive muskeg dominate this area. Exposures of Precambrian and Paleozoic rock and Quaternary sediments occur almost exclusively along river valleys, incised as the result of differential isostatic uplift over the last 8000 years (e.g., Nelson, Gods, Hayes, Fox, Stupart and Pennycutaway rivers). The rivers and creeks are commonly incised 30 to 50 m into the Quaternary sediments that blanket the area.

PREVIOUS WORK

Recent work on the Quaternary stratigraphy of the Hudson Bay Lowland of Manitoba by Nielsen et al. (1986), Berger and Nielsen (1990), Dredge et al. (1990) and Roy (1998) focused primarily on the geology along the Nelson River, downstream from Gillam. These studies highlighted the chronostratigraphy of the Quaternary deposits and only casual consideration was given to the lithostratigraphy of the tills in the area. Nielsen et al. (1986) outlined a stratigraphy comprising four tills and two non-glacial sequences, not including the present interglacial. The three uppermost tills were deposited by ice flowing out of Hudson Bay in a southwesterly direction, whereas the lowest till was deposited by southeasterly flowing ice originating in the Nunavut region, north of Manitoba. However, limited information is available on the extent and character of the tills in the Gillam area, across the Hudson Bay Lowland and adjacent northern Superior Province of Manitoba.

METHODS

Helicopter-supported fieldwork was undertaken during a three-week period in August, using Gillam as the central staging area. Of the numerous sections exposed along the Hayes, Gods, Pennycutaway, Fox, Stupart and other rivers and

creeks in the area, seven sections were selected for detailed investigation (Fig. GS-18-1). The seven sections, along the Lower Hayes River, were selected based on the availability of a suitable helicopter-landing site, nature of the geology, distance and relative spacing from other sites and proximity to previously surveyed areas in the northern Superior Province. Samples were collected at 2 to 3 m intervals in each of the seven sections. Two sample types were taken at each sampling interval: an 11 L sample was taken for kimberlite indicator-mineral and gravel analysis and a 2 kg sample was collected for geochemistry. Sixty-nine till and two coarse sand samples were collected from the seven sites for analyses. Pebble fabrics, consisting of 30 clasts each, were measured at 19 locations.

De Beers Canada Exploration Inc. extended their offer to concentrate, pick and analyze by electron microprobe the kimberlite indicator minerals free of charge. In keeping with our usual confidentiality practice, the sampling site locations are not revealed to De Beers or identified in the accompanying figures. Calcite and dolomite content will be determined at the laboratories of the Geological Survey of Canada in Ottawa. Pebble counts, textural analysis and geochemical analysis will be contracted out.

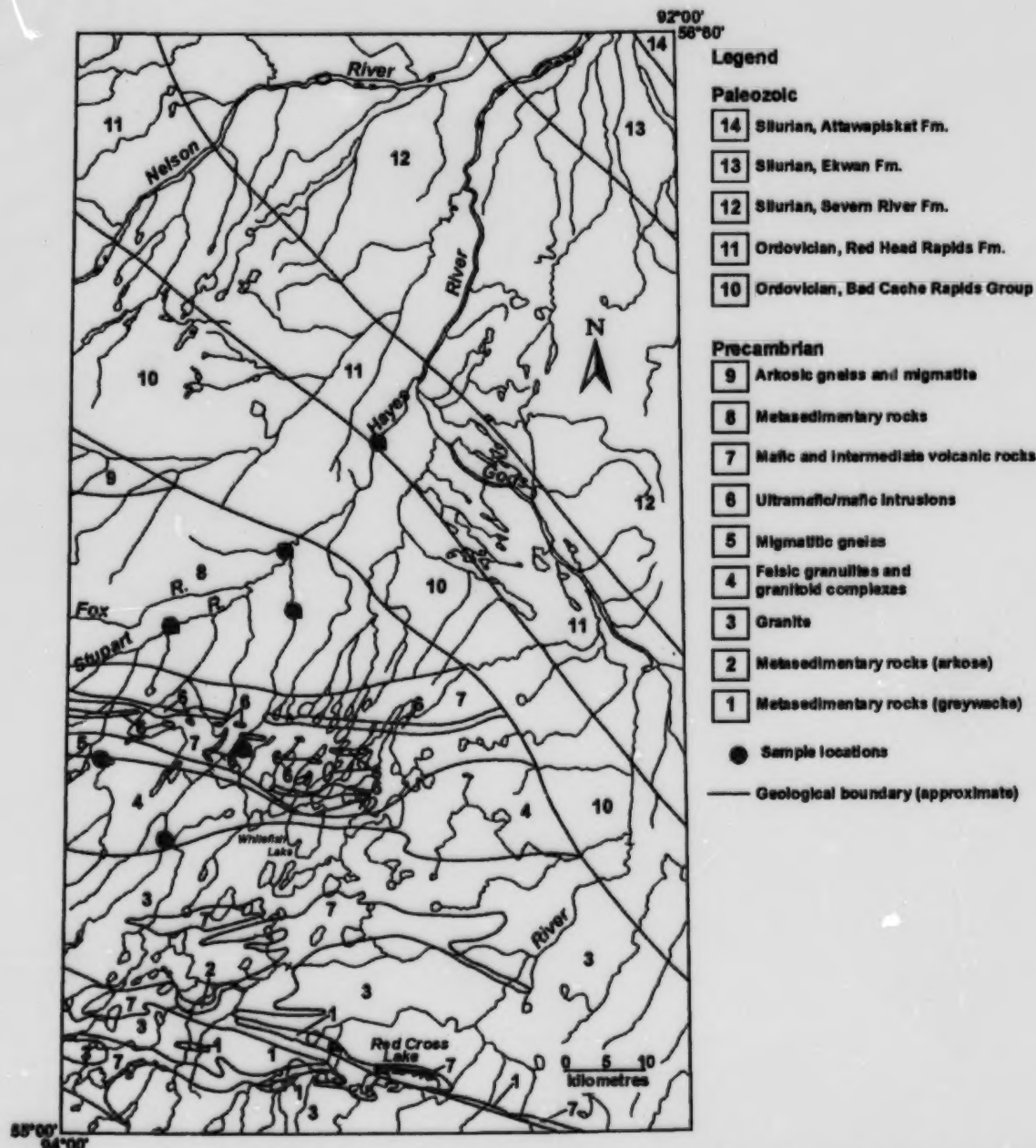


Figure GS-18-1: Location of the seven measured stratigraphic sections along the Lower Hayes River in the northern Superior Province and adjacent Hudson Bay Lowland.

RESULTS

The seven stratigraphic sections (Fig. GS-18-2) highlight thick till accumulations generally capped by glaciolacustrine silt and clay deposits, postglacial marine sediments and in places thick deposits of alluvium. Three distinct tills were identified in the field based on the colour and texture of the matrix and stratigraphic position. Pebble fabric measurements suggest a fourth till, not identified in the field, that may be present at the base of some sections. A composite stratigraphic section is presented in Figure GS-18-3.

The oldest till, exposed at the base of four sections, is olive-grey. It is finer textured than the overlying tills and at two sites underlies non-glacial sediments, interpreted to be Sangamon interglacial beds. This till has been tentatively correlated with the Amery till on the Nelson River based on its stratigraphic position. The Amery till has not been found in the multimedia surveys in the northern Superior Province. Nine samples were collected for analysis. Pebble fabrics measured at four sites give contradictory results: two fabrics indicate ice flow towards 255° and two fabrics indicate ice flow towards 115°. Striations on a boulder pavement at one site suggest ice flow towards 235° to 250°. Correlation with the Sundance till is also possible. Clearly, additional work is needed to determine the proper correlation and provenance of this pre-Sangamon till(s).

The overlying till is olive-grey and outcrops in all seven exposures examined. It is a fine-textured till that has not previously been seen in hand-dug pits in the northern Superior Province multimedia surveys and is correlated with the Long Spruce till on the Nelson River. Forty samples of this till were collected for analysis. Pebble fabrics measured at 10 sites record ice flow towards 195°, although there is considerable scatter in the orientations. Striation measurements on a boulder pavement at one site indicate ice flow towards 210° to 215°. Striations measured on bedrock exposed in the Stupart River, not far from one site and at approximately the same elevation as the base of the section, record ice flow towards 220°. These striations are not positively correlated with striations associated with the Long Spruce till.

The uppermost till is exposed in only four sections and is yellowish brown. This is the surface till throughout the Hudson Bay Lowland and adjacent parts of the northern Superior Province, but it is underrepresented in exposures along the river valleys because of erosion during postglacial valley incision. Similar fine-textured till was encountered in a few sites in the Knee Lake area (M. Fedikow et al., work in progress, 2001). It is correlated with the Sky Pilot till exposed along the Nelson

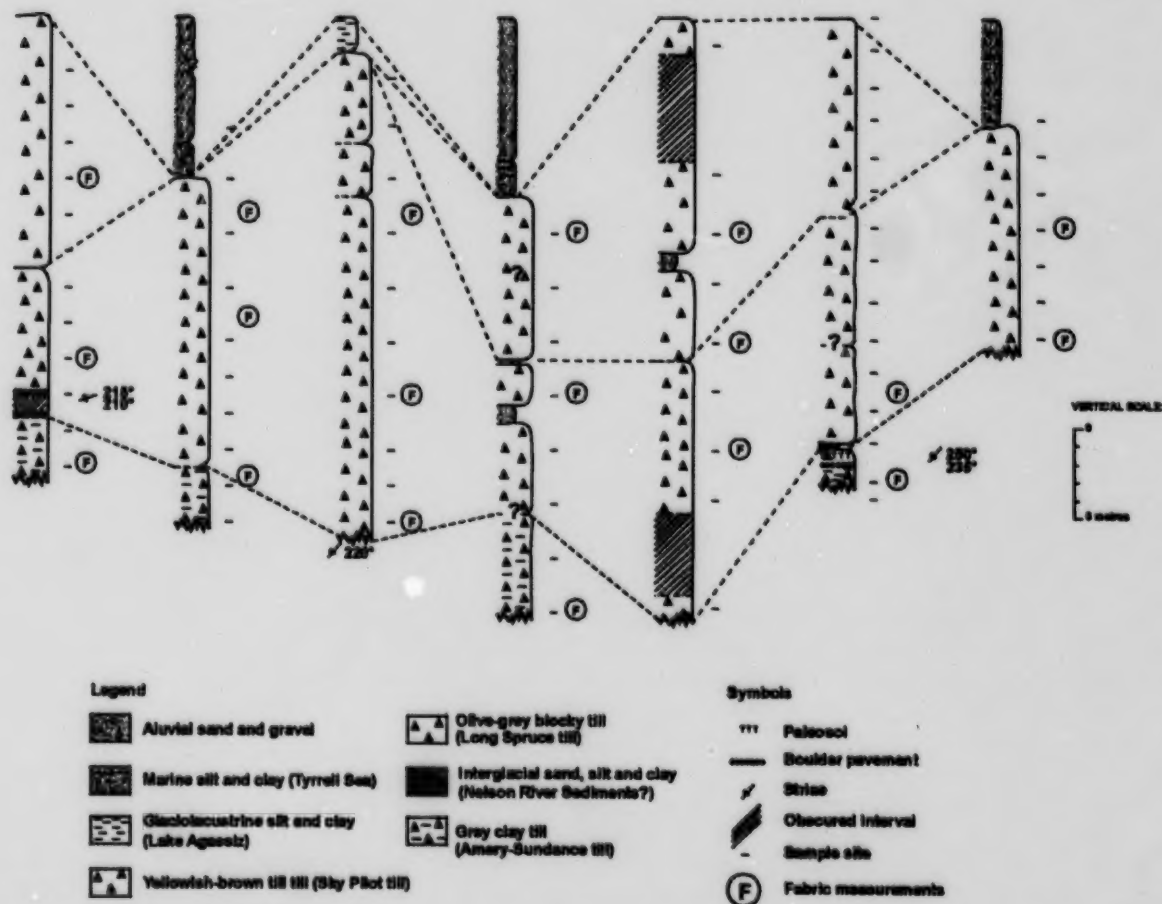


Figure GS-18-2: Quaternary stratigraphy and probable correlation of the seven sections along the Lower Hayes River.

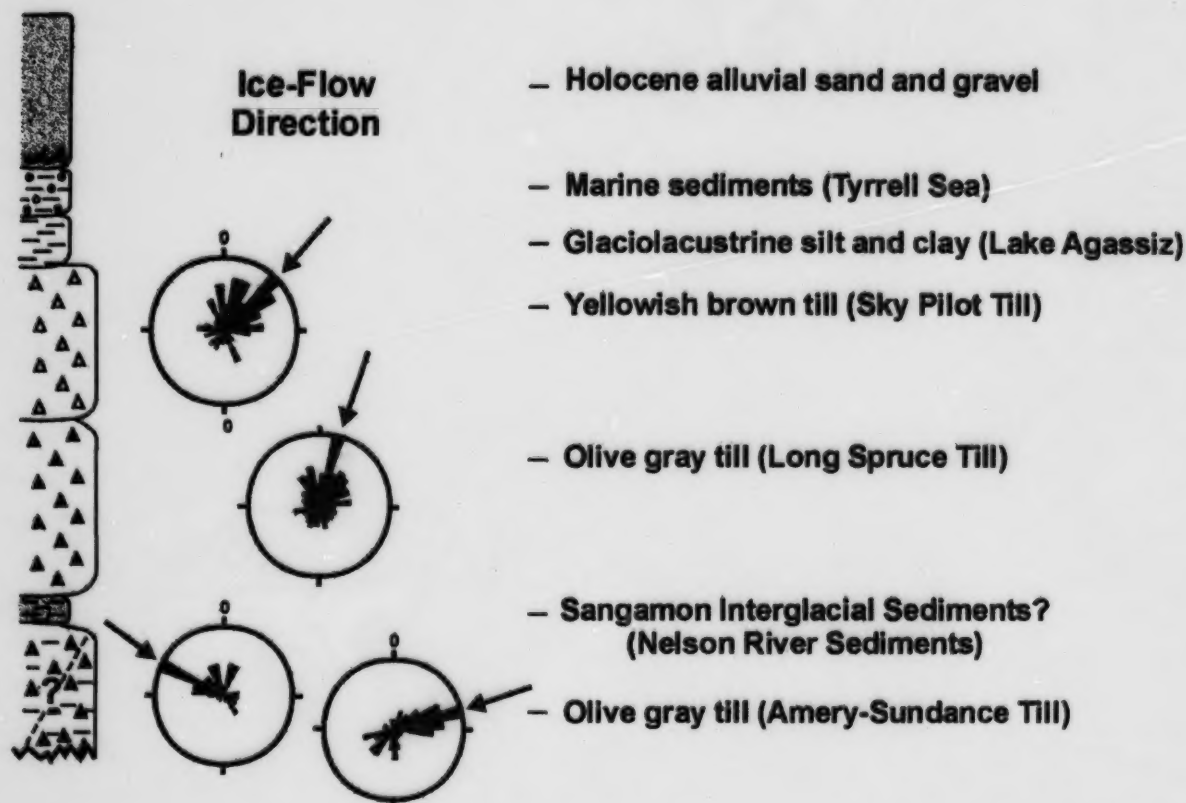


Figure GS-18-3: Composite stratigraphic section with ice-flow directions and correlation with Quaternary sediments along the Nelson River.

River. Twenty samples of this till were collected for analysis. Pebble fabrics measured at three sites indicate this till was deposited by ice flowing towards 225°, which is consistent with ice flow recorded in the Knee Lake area and elsewhere.

Four sections were capped by glaciolacustrine silt and clay deposited in glacial Lake Agassiz, fossiliferous marine sediments including gravel, sand, silt and clay deposited in the Tyrrell Sea and/or Holocene alluvial sand and gravel. Two samples of coarse, sandy alluvium were taken for kimberlite indicator-mineral analysis.

ACKNOWLEDGMENTS

Chris Bater and Ryan Oger were able and enthusiastic field assistants and I am indebted to them for their hard work and geologic insights throughout the summer. I also wish to thank our helicopter pilot, Alain Dejadins, Provincial Helicopters Ltd. (Lac du Bonnet) for his considerable skill and good judgment in piloting us safely. Alain's numerous talents, whether it was with helicopter, shovel or chainsaw, and his cheery disposition were much appreciated.

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SUMMARY

The Bird River Sill has been explored for chromite, Ni-Cu and platinum-group elements (PGEs). Past studies focussed on the Dumbarton-Maskwa Ni-Cu mine and the well-exposed and accessible Chrome property. Three PGE-bearing stratabound layers, two of them intimately associated with chromitite layers, were defined on the Chrome property in previous studies. A sulphide-bearing layer associated with chromitite layers, thought to be equivalent to the 'Disrupted Chromitite' layer on the Chrome property, was defined this summer on the Page property. This approximately 6 m thick sulphide-bearing layer, recognized on most of the Page property, is a conspicuous, easily traced marker horizon containing disrupted chromitite layers and a vast number of chromitite pebbles. These pebbles are thought to be the product of episodic disruption and fragmentation of solid chromitite layers. The chromitite fragments were abraded and rounded during transport and eventually deposited on a semisolid substratum of olivine crystals.

This model requires a magma chamber that is at least periodically dynamic and characterized by magmatic surges of sufficient momentum to fragment solid chromitite layers and transport the fragments over an undetermined distance that was sufficient to abrade and round the fragments. Such surges would generate turbulence in at least part of the magma. Periodic magmatic turbulence during emplacement of the Bird River Sill is highly significant for guiding the search of PGE-bearing layers. It is widely believed that many 'reef-type' PGE deposits were formed as a result of magmatic interaction due to the injection of a batch of sulphide-rich primitive magma into a chamber containing PGE-bearing magma. The ensuing turbulence of the magmatic reservoir is assumed to facilitate thorough mixing of both magmas, resulting in the efficient scavenging and concentration of chalcophile elements, including the PGEs. Resulting sulphide droplets are thought to concentrate in discrete layers or reefs.

INTRODUCTION

The Page property, approximately 2.5 km long, is located within the Bird River Sill in southeastern Manitoba, 2.3 km northeast of the Chrome property (Fig. GS-19-1). The Bird River Sill is a south-facing, ultramafic to mafic layered body that intruded Archean supracrustal rocks of the Bird River greenstone belt in the Superior Province. It consists of a lower, modally and cryptically layered ultramafic rock sequence, including dunite, peridotite, chromite and pyroxenite, overlain by anorthositic (and, in places, glomeroporphyritic) gabbro and anorthosite. Although disseminated chromite is ubiquitous throughout the ultramafic sequence, layers of chromitite (>80% chromite) are restricted to the upper section of the ultramafic sequence. Timmins et al. (1985) gave a U-Pb zircon age date of 2745 ± 5 Ma for the Bird River Sill.

Mineral deposit studies in the Bird River Sill traditionally focussed on chromite and Ni-Cu resources. Geological studies regarding the PGE potential were initiated by Theyer (1982). Geological mapping and research that centred on the well-exposed and accessible Chrome property identified three reef-type, PGE-bearing layers in the ultramafic part of the sill.

Part of the 2001 field season was spent documenting the geology of the Page property in order to:

- ascertain the degree of lithological and stratigraphic continuity between the Page and the Chrome properties; and
- identify, map and sample rock layers on the Page property considered to be analogous to PGE-bearing rock units on the Chrome property.

Investigations of the stratigraphy of the chromitite layers were especially emphasized, because two PGE-bearing layers on the Chrome property are closely associated with chromitite layers.

PREVIOUS WORK

Most geological studies of the Bird River Sill focussed on the well-exposed and readily accessible Chrome property. The Bird River greenstone belt and the Bird River Sill were mapped by Trueman (1971, 1980). Bannatyne and Trueman (1982) and Cerny et al. (1981) summarized these studies. Geological investigations in the 1940s and early 1950s concentrated on chromite (Bateman, 1943). From the 1950s on, interest switched to the exploration for Ni-Cu mineralization (Karup-Møller and Brummer, 1978), but the focus reverted to chromite in the early 1980s. Investigation of the PGE potential of the sill started in 1982, when the principal author chemically analyzed a channel sample sawed across the exposed mafic and ultramafic

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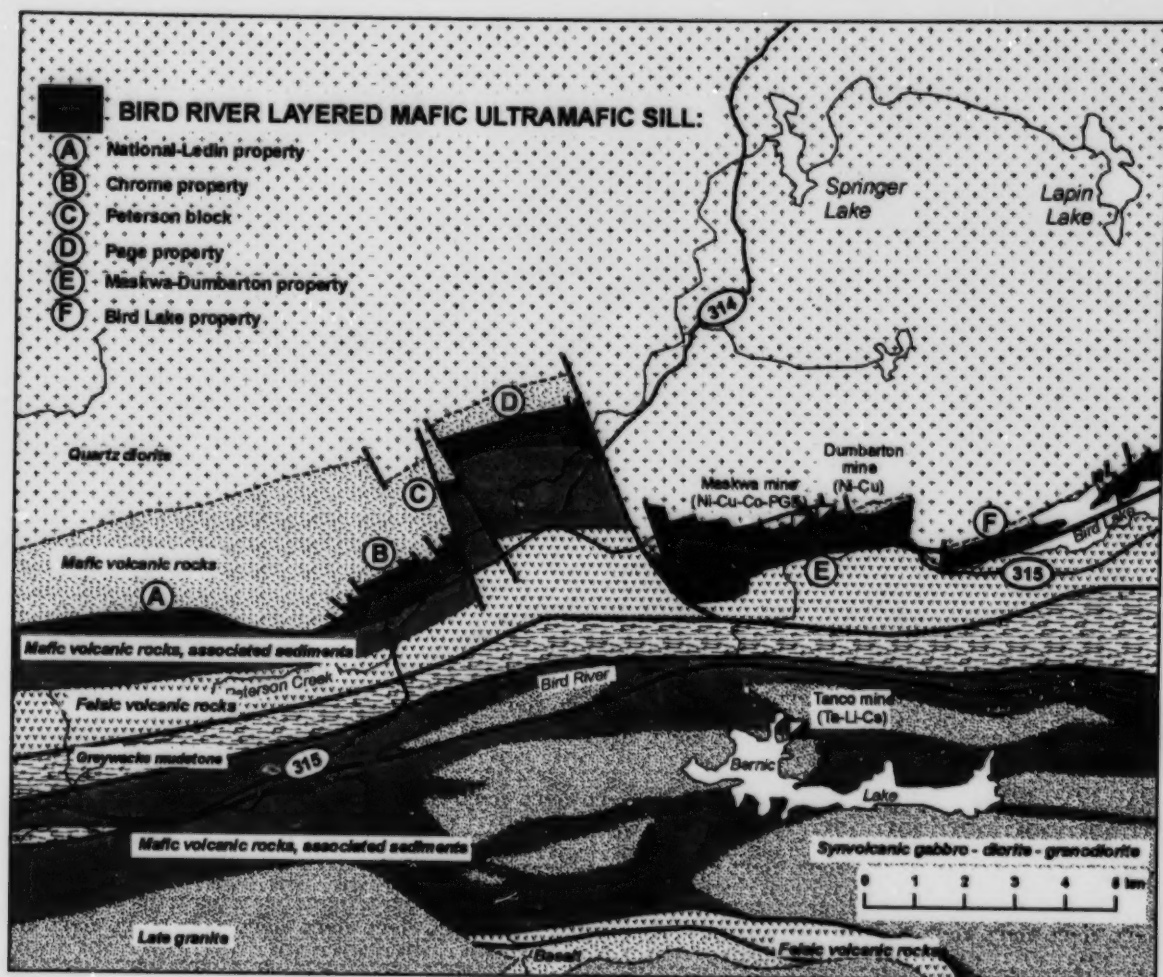


Figure GS-19-1: Location map of the Bird River Sill, showing the Chrome and Page properties.

portions of the sill on the Chrome property (Theyer, 1982). Platinum-group element inclusions in chromite from the Bird River Sill were described by Talkington et al. (1983). Theyer (1985) described two, metre-thick sulphide layers in the ultramafic portion of the intrusion, and Scoates et al. (1989) published maps and descriptions of two additional PGE-bearing layers, one associated with the 'Lower Group' chromitite and the other associated with the 'Disrupted Group' chromitite.

Peck and Theyer (1998) re-analyzed the material of Theyer's channel samples and presented further evidence of 'reef-type' PGE mineralization.

Young (1992) produced a (1:2000 scale) geological map and a report of the Page property, in which he noted that the stratigraphy of the chromitite layers is comparable with that of the Chrome property, which was defined by Scoates (1983).

STRATIGRAPHY OF THE CHROMITIFEROUS LAYERS

This year's investigations concentrated on the stratigraphy of the chromitite units on the Page property. Exposures on a hill near the eastern end of the Page property (Fig. GS-19-2) show a complex array of chromitite fragments derived from tectonically disrupted chromitite layers. The fragments range from 1 cm to several metres in length and are offset by faults. The magnitudes of displacement range from a few millimetres to more than 1 km. The faults are mainly dextral, but sinistral and wrench faulting were also observed.

The stratigraphy of the chromitite layers on the Page property is very similar to that established by Scoates (1983) for the chromitite units of the Chrome property.

Disrupted Chromitite Layer with Chromitite Pebbles and Sulphide Minerals (Part of Section A-A')

Section A-A' (Fig. GS-19-3A and -3B) presents a detailed view of the exposed rock types from north to south (i.e., from the stratigraphically lower to the stratigraphically higher units).

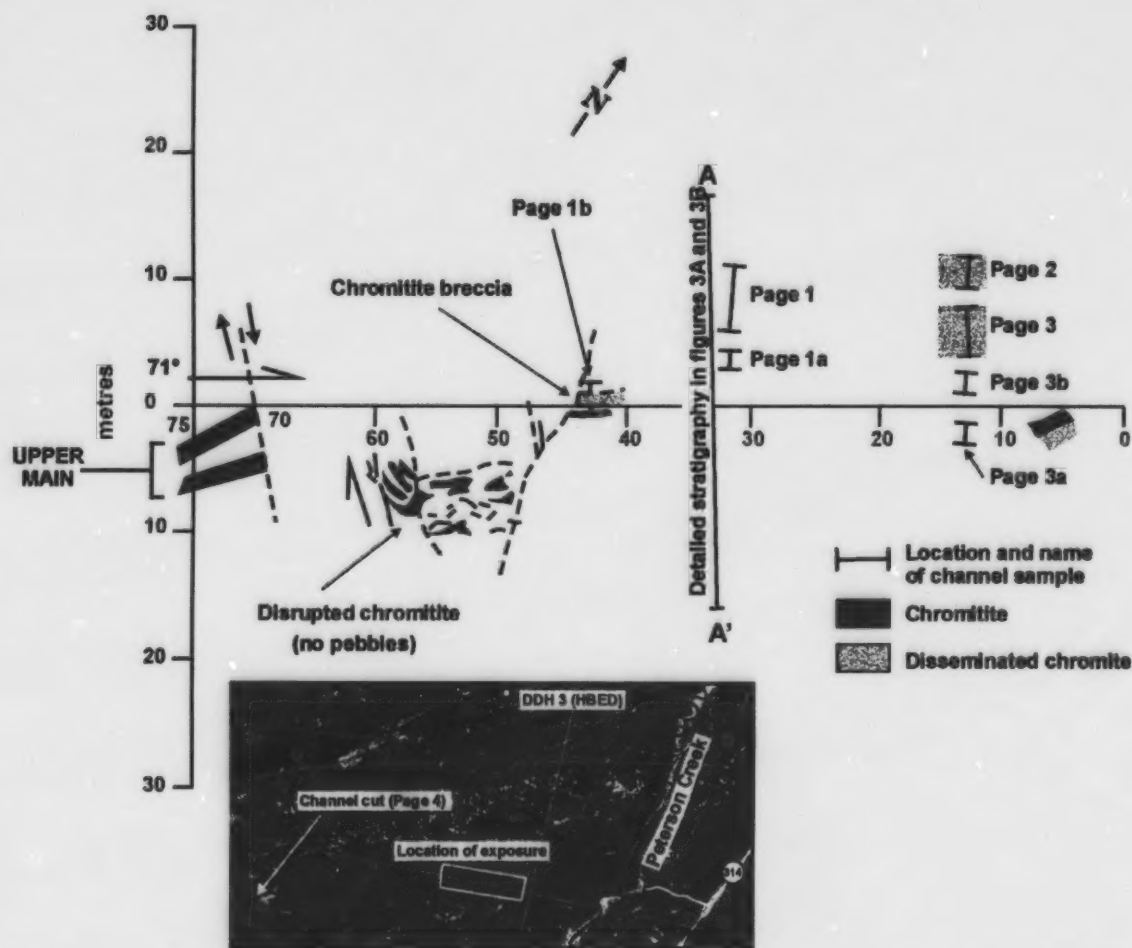


Figure GS-19-2: Schematic geology of part of the Page property and location of detailed cross-section. Insert map shows location of chromitite exposures, channel sample 'Page 4' and diamond-drill hole 3 (Hudson Bay Exploration and Development).

The northern 9 m of this section (Fig. GS-19-3A) includes olivine cumulate (dunite) containing ubiquitous disseminated chromite and numerous randomly arrayed, centimetre-thick, elongated chromitite layers ranging from 10 cm to a metre in length. These layers are characterized by typical soft-sediment deformation, including slumping and load casts, and evidence of deformed bedding, including truncation and folding. Many of the chromitite folds are truncated and bevelled, implying that they formed and were partially eroded before deposition of the overlying bed.

A prominent characteristic of this layer, so far recognized only on the Page property, is the inclusion of countless chromitite pebbles in ill-defined layers (Fig. GS-19-4). The pebbles are generally subrounded to rounded but, in places, are subangular and highly irregular in shape, ranging from a few millimetres up to 8 cm in diameter. Each pebble is characterized by a thin (<1 mm) 'crust' of conspicuously large chromite crystals that contrast with the smaller crystals in the interior of the pebble. Polished pebble cross-sections also show differences between the reflectance of the core and the crust, believed to be caused by differences in the chemical composition. These 'crusts' are more resistant to weathering and abrasion than the chromite in the interior of the pebble. As a result, the chromitite pebbles are conspicuous on weathered surfaces, due to their intense black colour, lensoid shape and rough weathering outlines. The pebbles are generally randomly distributed but, in places, are sorted into concordant zones and vaguely arcuate trains commonly demarcated by a layer of chromitite granules, several millimetres thick, that is interpreted to be the debris of ground chromitite pebbles (Fig. GS-19-5).

The chromitite pebbles are interpreted to be autoliths derived from the debris of rigid chromitite layer(s) that were disrupted and fragmented in a turbulent magmatic environment. Turbulence in the magma, resulting in differing transport velocities of the chromitite pebbles, is suggested by a chromitite pebble that indented and partially adhered to a second pebble (Fig. GS-19-6). The ubiquitous crust characteristic of the pebbles is interpreted as evidence that, after formation, the pebbles adjusted to conditions that differed from the physicochemical environment in which the chromitite layer was originally deposited. The rigid chromitite layers that disintegrated into fragments (which were subsequently rounded into pebbles) must have been located in a cooler part of the magma chamber. Indentations observed in the substrate of many of the pebbles is interpreted as evidence that the pebbles were deposited onto semiconsolidated cumulate olivine layers.

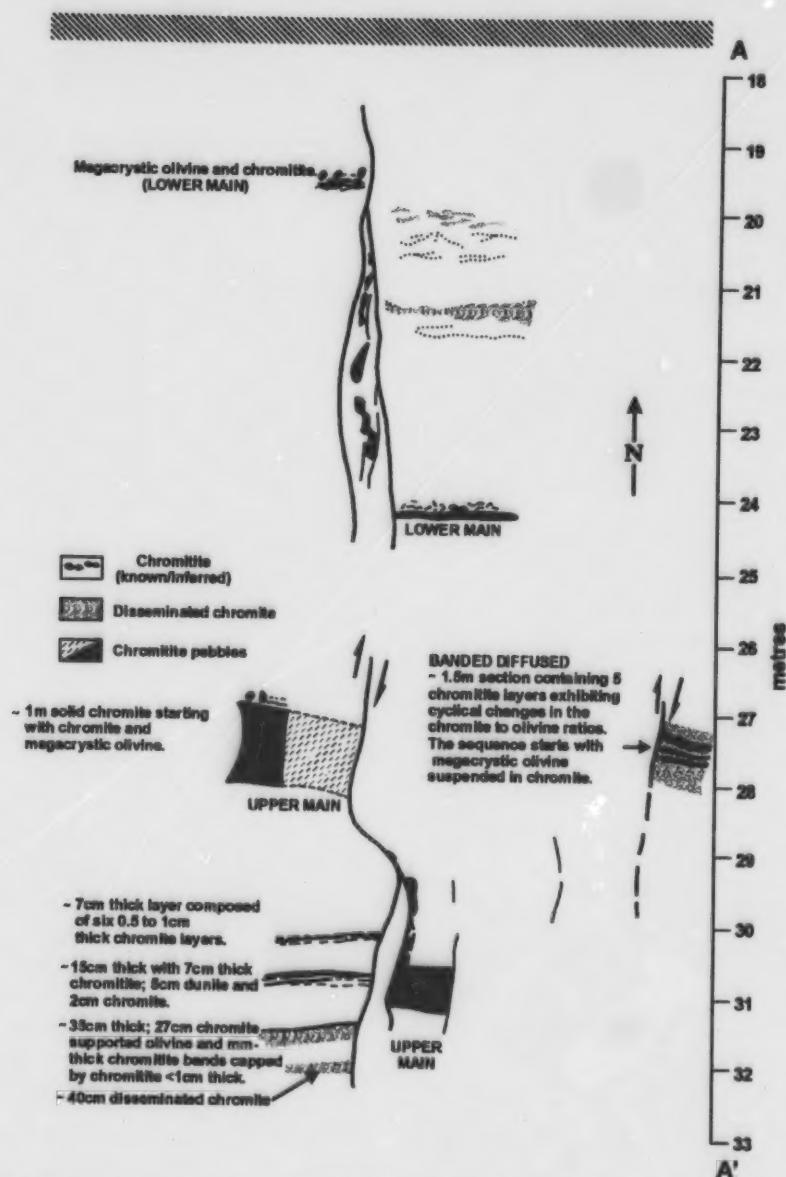


Figure GS-19-3A: Detailed geological section A-A', northern part. Note that true widths of the lithological units are less than portrayed, because the sill dips south at angles ranging from 55° to almost vertical and the outcrop surface slopes up to 30° toward the north.

Lithic fragments stopped from the top of a magma chamber by convecting magma, followed by deposition of the fragments on a crystal mush at the bottom of the chamber, has been described in the Skaergaard intrusion of Greenland (Irvine et al., 1998). This mechanism is considered as a possible model to explain the formation of the pebble-bearing layers.

The balance of the section consists of fragmented exposures of the 'Lower Main', 'Banded Diffuse', 'Upper Main' and 'Upper Paired' chromitite layers. The Lower Main chromitite layer is intensely fragmented along an approximately 5 m dextral fault trace.

ECONOMIC GEOLOGY

There is a correlation between the pebble-bearing disrupted chromitite layers of the Page property and sulphide content of the Bird River Sill. Concentrations of up to 5% pyrrhotite, with traces of pyrite and chalcocopyrite, were observed on slabs of channel sample 1-2001 (Fig GS-19-3B). Similar concentrations of pyrrhotite, with traces of pyrite and chalcocopyrite, were observed approximately 450 m west at the site of channel sample Page 4 (Fig. GS-19-2). This channel sample intersected pebble-bearing 'Disrupted Chromitite' layer and sulphide minerals, in amounts and distribution similar to those encountered in channel sample 1-2001. The discovery and tracing of a sulphide-bearing layer, associated with chromitite layers and

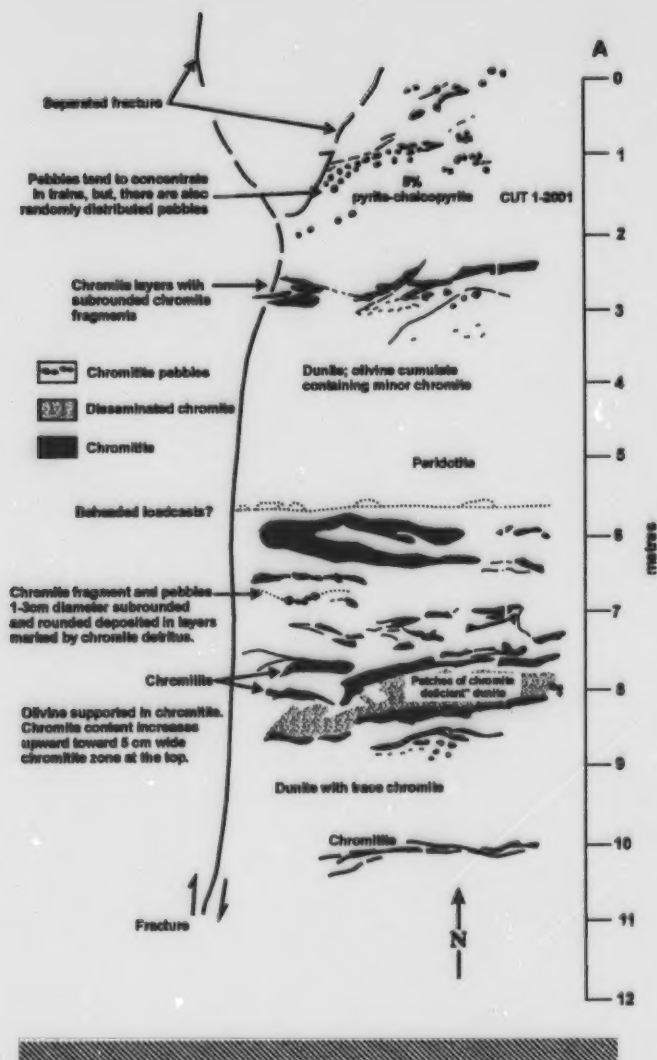


Figure GS-19-3B: Detailed geological section A-A', southern part. Note that true widths of the lithological units are less than portrayed, because the sill dips south at angles ranging from 55° to almost vertical and the outcrop surface slopes up to 30° toward the north.



Figure GS-19-4: Chromitite pebbles arranged in layers.



Figure GS-19-5: Disrupted chromitite layers and chromitite pebbles partially embedded in chromitite debris.



Figure GS-19-6: Chromitite collision! Note that one pebble indents the other; both pebbles remained welded to each other.

pebbles, that extends through most of the Page property is thought to be of economic significance. Magmatic turbulence is the hallmark of reef-type PGE concentration models (Naldrett, 1989). Geochemical data from rock units under discussion were not available at the time of writing.

In addition to the above-mentioned potentially PGE-bearing layer associated with the 'Disrupted Chromitite' layer, a second possible sulphide- and PGE-bearing layer occurs at the Page property. Diamond-drill hole 3 (Fig. GS-19-2), drilled by Hudson Bay Exploration and Development (HBED) in 1954, intersected what is possibly the equivalent of the PGE- and sulphide-bearing layer at the base of the 'Layered Zone' on the Chrome property (Theyer, 2000). This drillhole, which aimed to test an approximately 600 m long, west-striking geophysical anomaly, intersected a 4.6 m thick sulphide zone containing up to 1.43 % Ni and 1.38 % Cu. Combined Pt+Pd content is up to 7.2 g/t over 20 cm.

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SUMMARY

A visit was made to view and sample Precambrian monadnocks northeast of Beausejour. All sites visited lie east of the Precambrian–Paleozoic boundary and consist of Precambrian granite of the Lac du Bonnet batholith. The rock outcrops rise 5 to 20 m above the surrounding prairie level and align in a linear fashion, trending approximately 020°. These sites have been known in the literature for many years and have been studied previously, but three-dimensional mapping in the Winnipeg region has confirmed that there are anomalous elevations. Since it appears that faulting may have occurred at Green Oak (north of Beausejour), these sites were visited for the sole purpose of collecting large samples for apatite fission track thermochronology, in the hope that the results would provide clues to the origin, tectonics and hydrocarbon–metallic–mineral generation of the Williston Basin.

GENERAL GEOLOGY

The study area is underlain by Precambrian rocks, with the limit of Paleozoic sedimentary strata occurring at a north-trending boundary dissecting the area (Fig. GS-20-1). The Precambrian rocks consist of extensive bodies of granite and granite gneiss. The Precambrian monadnocks visited occur northeast of Beausejour (Fig. GS-20-1), on the Precambrian side of the eastern limit of Paleozoic strata, approximately 2 to 12 km east of the Precambrian–Paleozoic boundary. The monadnocks consist of Precambrian granite typical of the Lac du Bonnet batholith. Previous mapping of these outcrops was done by McRitchie (1969a, 1969b) and Schmidtke (1994). Regional stratigraphic dips are usually less than 3 m/km (McCabe, 1983).

Local Bedrock Geology

Local bedrock geology consists of Precambrian and Ordovician rocks. The Precambrian rocks are mainly granite and granite gneiss of the Superior Province. The Ordovician rocks, which dip to the southwest, comprise two formations: the older Winnipeg Formation and the younger Red River Formation.

The Red River Formation strikes north to north-northwest and is exposed in outcrops and quarries near Garson (Fig. GS-20-1). It consists of mottled, dolomitic limestone containing abundant fossiliferous material, such as cephalopods, gastropods, corals and *Receptaculites*.

The Winnipeg Formation also strikes north to north-northwest across the study area and outcrops at Victoria Beach and along the west side of Lake Winnipeg (Hecla and Black Islands). It consists of rounded, medium-grained, quartz-rich sandstone interbedded with olive-green shale.

The Lac du Bonnet batholith forms the dominant igneous rock body in the area. It is composed of a pink, finely to coarsely crystalline granite. Metavolcanic and metasedimentary rocks are also found in a number of narrow, east-trending belts.

MONADNOCKS

Monadnocks are described as isolated hills or residual rocks rising conspicuously above the general level of a peneplain. They are erosional remnants of the original surface. The seven sites visited (Fig. GS-20-1) exhibit relief of 5 to 20 m (Fig. GS-20-2, GS-20-3), but adjacent coreholes indicate actual relief to be as much as 40 to 55 m above the regional unconformity surface. Site R8S may have near-surface bedrock, which would probably be Precambrian in age. Future drilling of site R8S would likely confirm the presence of near-surface bedrock. See Table GS-20-1 for more details on each site.

Unique, circular features were found at site R4S (Fig. GS-20-4). They range from 10 to 25 cm in diameter, are concave (3 to 5 cm deep) and some have 1 to 2 cm wide raised rims. Some occur in clusters of up to three depressions. It was not determined whether they represent features inherent in the rock or are archeological features. The raised rims, though, may preclude them from being archeological features. They are probably not postglacial features because raised rims would likely have been eroded during glaciation. They may represent fallout from a meteor.

BEDROCK TOPOGRAPHY

The Precambrian monadnocks outcrop in a linear pattern that trends north-northeast. They occur at elevations ranging from 230 to 238 m. The contact between the Winnipeg Formation and the Precambrian varies from 205 to 213 m in elevation. Individual outcrops of granite exhibit relief of 5 to 20 m above the neighbouring fields, but coreholes adjacent to these outcrops indicate additional relief of up to 35 m above the regional unconformity surface (McPherson, 1970; McCabe, 1983). These outcrops are approximately 20 km farther west than other Precambrian outcrops in the area. Regional structural data

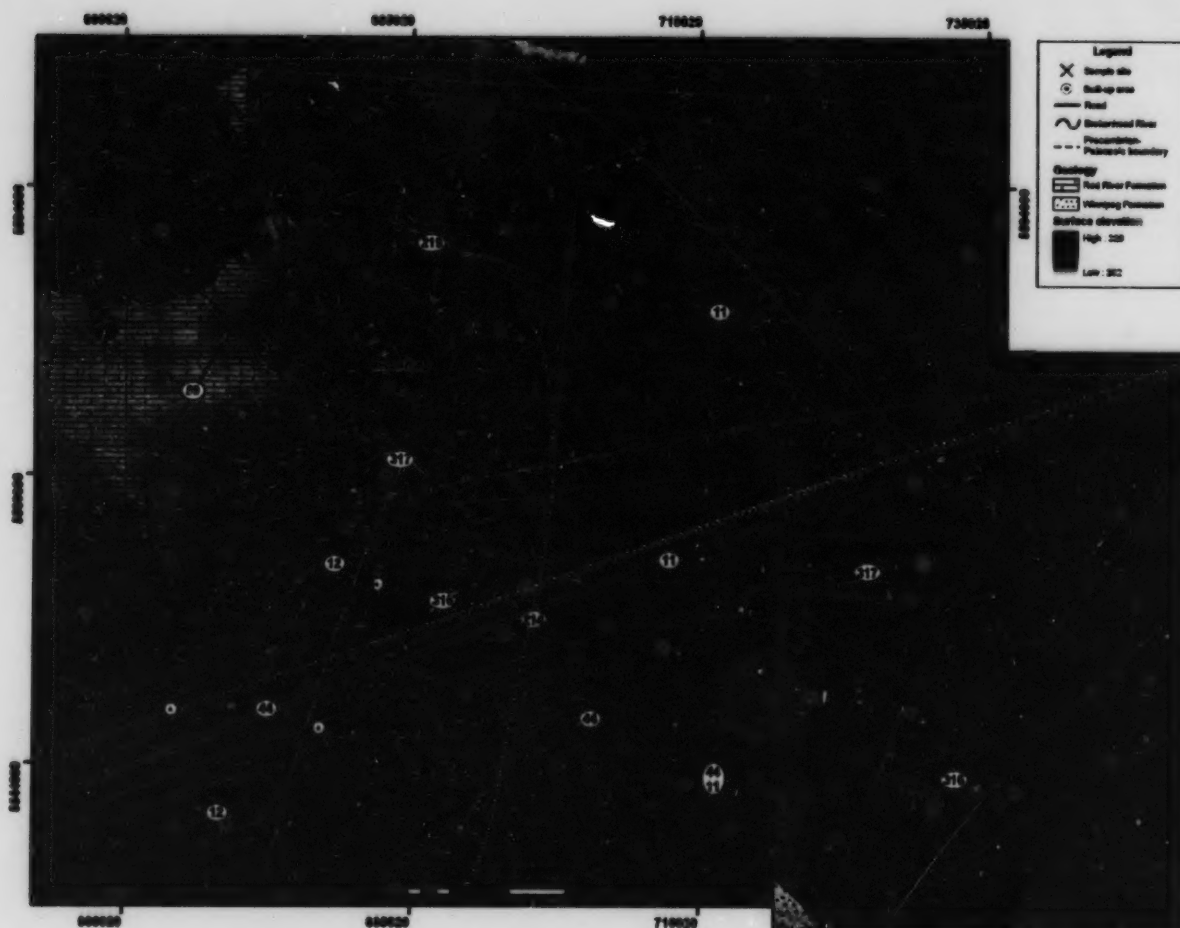


Figure GS-20-1: Digital elevation model of the study area, showing monadnock sample sites and location of cross-section A-A' (see Fig. GS-20-5).



Figure GS-20-2: Sample site R6S, next to farmyard, looking northeast.



Figure GS-20-3: Sample site R7S, next to farm field, looking northeast.

Table GS-20-1: Details of monadnock sample sites.

Sample ID	Map ID # ¹	NTS	UTM		Elevation (m)	Height (m)	Size	Comments
			Northing	Eastings				
88-01-02	R1S	62V/1	5559500N	684900E	234.9	-10	Medium	
88-01-03	R2S	62V/1	5565300N	685900E	238.4	15-20	Very large	
88-01-04	R3S	62V/1	5565800N	685900E	234.0	7-10	Medium	
88-01-05	R4S	62V/1	5566200N	686100E	233.6	10-15	Medium	Circular features
88-01-06	R5S	62V/8	5572154N	688649E	234.8	5-7	Small	
88-01-07	R6S	62V/8	5566664N	688554E	230.8	-5	Small	
88-01-08	R7S	62V/8	5577712N	690234E	232.6	5-10	Medium	
88-01-09	R8S	62V/8	5576357N	691833E	237.1	?	Small	No outcrop present

¹on Figure GS-20-1

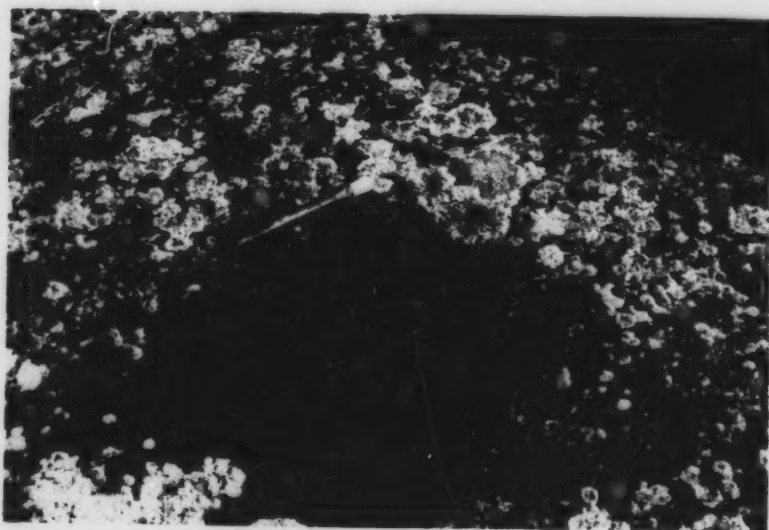


Figure GS-20-4: Circular feature with raised rim at site R4S.

suggest that these granite outcrops are at least 35 m higher than normal in the Green Oak area (McCabe, 1983).

Drilling was conducted by McCabe in 1983, 3 km due west of the Precambrian monadnock R1S (Fig. GS-20-5). The first corehole, M-2-83, intersected a thick sequence (29.7 m) of glacial sediments that rests directly on partially brecciated shale and sandstone of the Winnipeg Formation. The Winnipeg Formation was only 7 m thick in this corehole. The elevation of the Precambrian surface is close to that predicted by regional extrapolation. The second corehole, M-3-83, was located beyond the eastern limit of Paleozoic rocks in the area. After penetrating approximately 35.3 m of glacial sediments, it intersected Precambrian basement at an elevation approximately the same as in hole M-2-83. Lithology of the Precambrian in both holes is the same as in the granite outcrop to the east: massive pink granite typical of the Lac du Bonnet batholith. The third corehole, M-4-83, was to be drilled through the entire Paleozoic sequence into the Precambrian. Unfortunately, after penetrating

the Red River Formation, drill rods jammed in a shale bed close to the top of the Winnipeg Formation and the hole could not be completed. In coreholes M-2-83 and M-3-83, the Precambrian surface appears to be at an elevation close to that expected for this area. East of this, an abrupt rise of at least 43 m occurs over a distance of 2.8 km, giving a gradient of 15 m/km. Regional gradients are usually less than 3 m/km (McCabe, 1983).

McCabe (1978) suggested that these Precambrian highs constituted structural-topographic islands during early Paleozoic (Winnipeg Formation) time, and drastically affected deposition of the Winnipeg strata. He also suggested that the abruptness of the features, and almost complete lack of other erosional relief on the Precambrian surface elsewhere in southern Manitoba, strongly suggest that the Green Oak paleotopographic high is structurally (?fault) controlled. The structure most likely developed during late Precambrian or even early Paleozoic time; otherwise, it would have been truncated by pre-Ordovician erosion.

Green Oak is not the only place along the present Paleozoic edge where anomalous relief is evident on the Precambrian surface. A similar feature is present near Beausejour, where drilling has indicated a bedrock low of approximately 35 to 40 m (Michalyna et al., 1975; Lebedin, 1978; Young, 1982). It is interesting to note that the Brokenhead River coincides with the Beausejour and Green Oak anomalous sites, and appears to follow what may be a zone of weakness (i.e., the Paleozoic-Precambrian boundary trough). Anomalous relief on top of the Precambrian is also present at The Narrows on Lake Winnipeg, where the Precambrian rises approximately 21 m over a distance of 2.2 km (McCabe, 1983).

APATITE FISSION TRACK (AFT) THERMOCHRONOLOGY

A comprehensive apatite fission track (AFT) thermochronology study of the basement underlying the Williston Basin, its environs and the adjacent Precambrian Shield has been undertaken by a group of researchers, including the Geological Survey of Canada (Calgary) (Feinstein et al., 2000). Intracratonic basin tectonics remains a problem of economic significance. Thermal history variations, which can be measured by AFT thermochronology, control petroleum generation in the Williston Basin, and probably metallic-mineral generation in Phanerozoic sediments. Using AFT thermochronology, investigators have identified a thermal effect accompanying intracratonic basin subsidence. Clues to the origin, tectonics and hydrocarbon-metallic-mineral generation and emplacement history of the basin can be obtained using AFT thermochronology.

ECONOMIC IMPLICATIONS

As previously mentioned, thermal-history variations control petroleum generation and metallic-mineral emplacement in the Williston Basin. An understanding of structural tectonics in the basin is crucial in solving these problems. Southard (1978) conducted early work in the area on the economic implications for uranium. An environment favourable for uranium concentration within the Winnipeg Formation, at or near its contact with Precambrian granite, includes a zone extending from

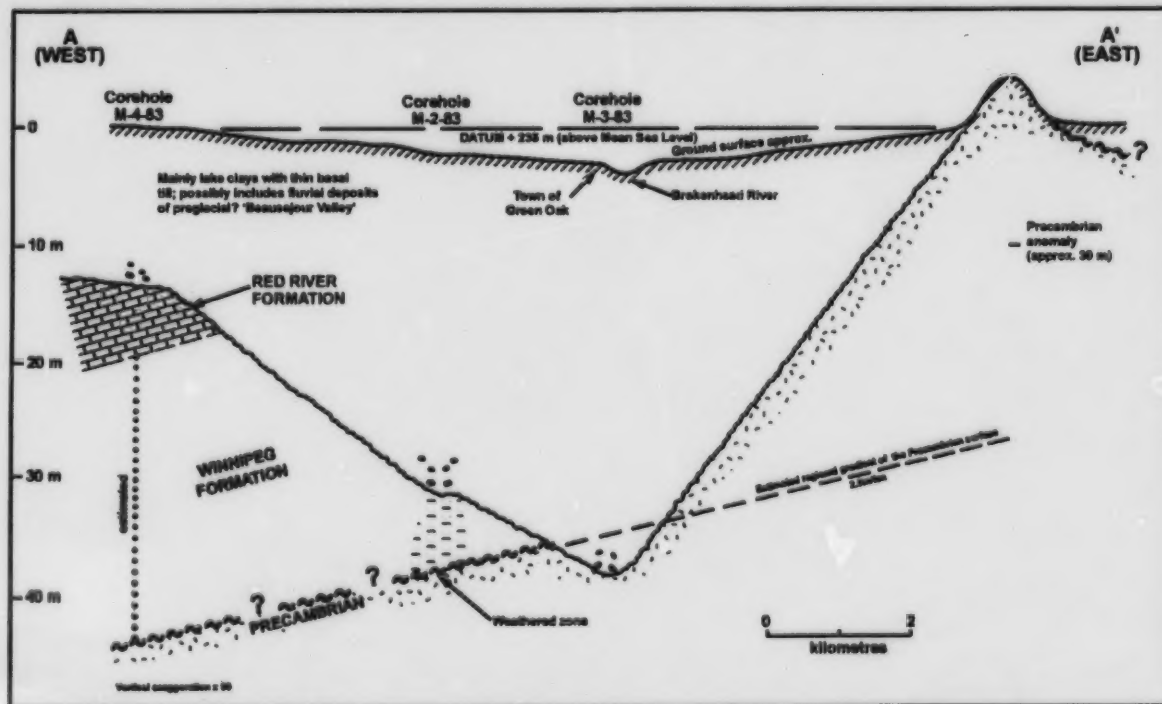


Figure GS-20-5: Cross-section A-A', indicating a Precambrian high at sample site R1S. See Figure GS-20-1 for section location.

the southern end of Lake Winnipeg into the United States (along the Precambrian-Paleozoic boundary). In this study, a total of 176 water wells were sampled and analyzed for Eh, pH, Pb, Cu, Zn, Fe and ^{222}Rn . Southard's data indicate anomalous radon concentrations in a 7 km² area northeast of Beausejour. The high uranium values encountered could not be explained simply by uranium leached from the bordering granite terrain, suggesting that a source of concentrated uranium is probably present in the area.

Betcher et al. (1988) conducted a study of uranium in groundwater in southeastern Manitoba and reported high levels of the element in water wells sampled. Of the wells completed in the Precambrian bedrock, 61% had uranium concentrations above 20 µg/l (the recommended maximum concentration for Canadian drinking water). Maximum uranium concentrations (up to 2020 µg/l) are comparable to some of the highest levels measured worldwide. Groundwater in the overlying surficial Lake Agassiz clay also contained high concentrations of dissolved uranium. Uranium in groundwater associated with Lake Agassiz clay is thought to be brought into solution primarily by release from organic material during oxidation, followed by the formation of stable uranyl-carbonate (Betcher et al., 1988). Leakage of groundwater from Lake Agassiz clay into Precambrian rock aquifers was shown to provide a significant source of dissolved uranium to the groundwater in the Precambrian rocks, accounting for the coincidence of areas of high uranium concentration in both overburden and Precambrian rock aquifers. The Precambrian rocks also appear to serve as a significant source of dissolved uranium, probably by oxidation of reduced uranium (Betcher et al., 1988).

CONCLUSIONS

Apatite fission track thermochronology will be carried out on rock samples from seven Precambrian monadnocks. The results will be useful in helping to determine the heating history of this part of the Williston Basin and establish evidence of tectonic disruptions along the Precambrian-Paleozoic boundary. The data will also help establish patterns of petroleum generation and metallic-mineral generation and emplacement in this portion of the Williston Basin.

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GS-21 PHYTOREMEDIATION OF MINE TAILINGS AND BIO-ORE PRODUCTION: RESULTS FROM A STUDY ON PLANT SURVIVAL AT THE CENTRAL MANITOBA (AU) MINESITE (NTS 52L/13)

by S. Renault¹, E. Sailerova² and M.A.F. Fedikow



Renault, S., Sailerova, E. and Fedikow, M.A.F. 2001: Phytoremediation of mine tailings and bio-ore production: results from a study on plant survival at the Central Manitoba (Au) minesite (NTS 52L/13); in Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 138-149.

SUMMARY

A new project to determine the potential for phytoremediation of mine tailings and production of bio-ores, through the identification of plant species that can accumulate heavy metals, was initiated in 2000 at the Central Manitoba (Au) minesite in southeastern Manitoba (Fig. GS-21-1). The first phase of the project involved planting seeds and/or seedlings of 14 plant species on three experimental sites on mine tailings. Preliminary results have shown that several plant species were able to survive and grow for two growing seasons on two of the three selected sites without any remediation of the soil. Capping of tailings with peat allowed survival of all seedlings for at least one growing season on all experimental sites, including one site with very high Cu and Au contents. The growth and survival of Indian mustard in this environment indicates high potential for phytoremediation and possibly phytomining for this species. The amount of extracted base and precious metals from plants growing on tailing sites for two growing seasons should identify plant species that are suitable for phytoremediation and the production of a bio-ore. Preliminary results from analyses of plants growing on tailings for one growing season indicate substantial enrichment in Au in pine and spruce seedlings and enrichment in Zn in willow.

INTRODUCTION

Mining and mineral-processing activities contribute significant quantities of heavy metals to the environment and affect surrounding land, air and water quality. These effects cannot be reversed by nature and require aggressive application of planned reclamation programs.

Metal mines across Canada produce large amounts of tailings that represent the waste products of mine operations. The decreased pH of the tailings, caused by oxidation in air under moist conditions, leads to increased solubility of most heavy metals. Metal mobilization from tailings can often be traced into watersheds downstream from active minesites. Low pH, presence of metals in toxic quantities and the lack of vegetative cover and organic nutrients prevent seed germination and plant growth. Tailings thus form large areas without vegetation cover (Fig. GS-21-2) and are a source of enormous dust production. This dust in turn pollutes vast areas adjacent to the tailings creating additional environmental and possible health hazards. Affected soil cannot be used for agricultural purposes because of the high metal content and other land uses are limited. Today's practices of removing contaminated soil (excavation) are very expensive (Giasson and Jaouich, 1998).

Oxidation of the tailings can be controlled by covering the surface with soil and then usually revegetating the site. Establishment of a self-sustaining mat of vegetation is usually an important element in a rehabilitation program for waste-disposal areas. Vegetation stabilizes the soil, prevents new acid-generating material from being exposed, and decreases the amount of water available for deep percolation through transpirational water movement. Vegetation is established by controlling pH near the surface with addition of lime or limestone and by adding peat and fertilizers where necessary. This treatment can increase initial plant survival rate and help to induce adaptation processes. Plant species are usually selected from well-adapted species growing in the region (Bradshaw, 1952). Nevertheless, revegetation alone does not stop acid drainage and does not necessarily remove heavy metals from the contaminated site. Plant species and techniques successfully used in tailings remediation could be used to successfully remediate other contaminated soil sites.

Phytoremediation of soils contaminated with heavy metals is being developed as a potential cost-effective remediation solution for thousands of contaminated sites in the United States and abroad (Salt et al., 1995, 1998; Cunningham et al., 1995; Comis, 1996). Phytoremediation of tailings, however, is a problem that remains to be addressed on a case-specific basis.

A relatively new approach to phytoremediation involves the introduction of highly tolerant species with high biomass production capable of accumulating 0.5 to 1% of their dry weight in metals. Anderson et al. (1999) provides a list of hyperaccumulators under investigation. The shoots of these plants are harvested at the end of the growing season and burned, forming a metal-rich bio-ore (Nicks and Chambers, 1998). Up to 57 mg/kg Au (dry mass) could be accumulated by Indian mustard (*Brassica juncea*) (Anderson et al., 1998) using induced hyperaccumulation by ammonium thiocyanate, which is biodegraded to ammonia, bicarbonate and sulphate. The choice of hyperaccumulator species must also be climate and site specific, and sensitive to regulations restricting the introduction of foreign species.

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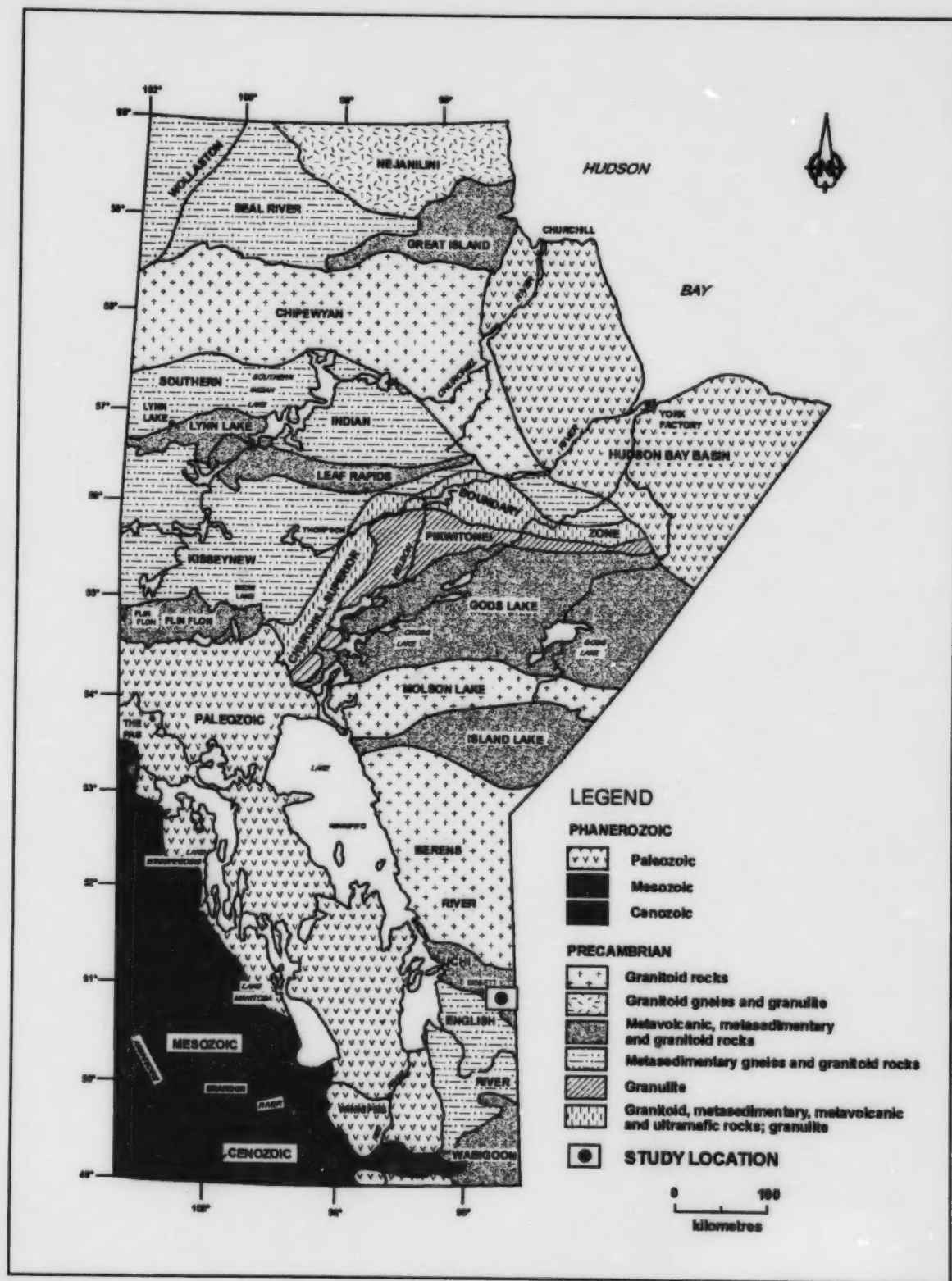


Figure GS-21-1: Location of the phytoremediation and phytomining study area, Central Manitoba gold mine, Bissett area, south-eastern Manitoba.



Figure GS-21-2: Central Manitoba gold mine tailings.

Phytomining technology offers the possibility of exploiting ores or mineralized soils that are uneconomic by conventional mining methods. Bio-ores are virtually sulphur-free and their smelting requires less energy than sulphide ores. The metal content of a bio-ore is usually much greater than that of a conventional ore and therefore requires less storage space, despite lower density. Moreover, phytomining is an environmentally responsible approach to site remediation.

OBJECTIVES

The long-term goal of this study is to define limiting factors for phytoremediation of mine tailings and other sites contaminated with heavy metals. This study will establish the scientific basis for the remediation of mine tailings and extraction of heavy metals by phytomining techniques. Practical experience would be gained in the routine remediation of mine tailings and possibly in the extraction of heavy metals. Plant species selected for the study will include plants native to the surrounding environment and seeds of plants acclimated on-site will also be tested. The suitability of selected species for phytomining for base metals and gold will be tested in terms of the quality and costs of bio-ore production and economic effectiveness.

SIGNIFICANCE OF THE WORK

Soil contamination by heavy metals, and metal leakage and dust production from sulphide tailings represents a significant and widely recognized ecological hazard. Phytoremediation offers the possibility of an ecologically acceptable and cost-effective solution. Phytomining, a new technique for extracting metals from low-grade ore or sulphide tailings, is a promising technique currently being developed for commercialization in the United States. Field experiments in phytomining in Manitoba could provide valuable information regarding the potential of this method to remediate sites contaminated with heavy metals.

GEOLOGICAL SETTING OF THE CENTRAL MANITOBA (AU) DEPOSIT

Tailings associated with the Central Manitoba gold deposit were selected for initial phytoremediation and phytomining studies. The deposit occurs within the Archean Rice Lake greenstone belt, in the Uchi Subprovince of the Superior Province in southeastern Manitoba (Fig. GS-21-1). The belt is flanked to the north by the Wanipigow River plutonic complex (Marr,

1971; Weber, 1971) and, to the south, is transitional with the Manigotagan gneissic belt (McRitchie and Weber, 1971; Weber, 1971). The Rice Lake belt is fault bounded by the Wanipigow Fault on the north and on the south by the Manigotagan Fault.

Host rocks to the deposit occur within the Bidou Lake subgroup (Poulsen et al., 1996) and comprise arkose, tuff and chert of the Dove Lake Formation. These sedimentary rocks have been intruded by gabbro sills. Gold-bearing quartz veins at the deposit are situated within en échelon shear zones at or close to the contact between the Dove Lake sedimentary rocks and an east-southeast-trending gabbro sill (Stockwell and Lord, 1939). Five veins contributed the bulk of production at the deposit. These were the Kitchener, Eclipse, No.1 Branch, Tene 6 and Hope veins. The quartz veins were mineralized with chalcopyrite, pyrite, pyrrhotite and free gold. Between 1928 and 1938, a total of 347 801 t of ore was milled and 4287 kg of gold produced.

GEOCHEMICAL CHARACTERIZATION OF THE TAILINGS AND DESCRIPTION OF EXPERIMENTAL SITES

Three experimental sites were chosen based on the proximity to the tailings edge and vegetation cover, exposure to sun and wind and drainage conditions (Sailerova, 2000). Site 1 was positioned relatively far from the tailings edge, partially sheltered by sporadic vegetation cover and poorly drained. Site 2 was located in the middle of the tailings mass with no vegetation cover, fully exposed to the wind and sun, and well drained. Site 3 was located close to the tailings edge, relatively well sheltered and drained. The pH values measured at the three experimental sites were 4 to 5 at site 1, 4 at site 2 and 5 to 7 at site 3.

Results of geochemical analyses of 20 tailings samples collected from three hand-augered profiles, each approximately 1 m in depth, were presented in Renault et al. (2000). The instrumental neutron activation analysis (INAA) total data indicate the relative base- and precious-metal enrichment in tailings at the minesite. In particular, Au was elevated in the upper 15 cm of the tailings profile at site 1 (3450 ppb), is consistently enriched throughout the profile at site 2 (1110–2640 ppb) and is somewhat lower but elevated at site 3 (265–958 ppb). Exceptional concentrations of Cu are documented from all three sites (834–5740 ppm at site 1, 1710–10 500 ppm at site 2 and 3150–4510 ppm at site 3). Additional enrichments of Ag (up to 6 ppm) and Bi (up to 127 ppm) are documented at site 1. Arsenic is low (<2–20 ppm) at all three sites.

RESULTS

Field Study: Plant Species Survival

Seedlings of native plant species of the boreal forest were selected for the study. In July 2000, the following tree species were planted on the three different sites described above: red-osier dogwood (*Cornus stolonifera*), yellow willow (*Salix lutea*), white spruce (*Picea glauca*), jack pine (*Pinus banksiana*), tamarack (*Larix laricina*) and bog birch (*Betula glandulosa*). In June 2001, additional red-osier dogwood (*Cornus stolonifera*), yellow willow (*Salix lutea*), white spruce (*Picea glauca*) and jack pine (*Pinus banksiana*) seedlings were planted on the three sites. Prior to planting in June 2001, a layer of peat (5 cm deep) was added on the top of the tailings on site 2. Seeds of the following species were also planted directly on tailings or after addition of peat at the three sites: Indian mustard (*Brassica juncea*), white mustard (*Sinapis alba*), slender wheatgrass (*Agropyron trachycaulum*), altai wildrye (*Elymus angustus*), reed canary grass (*Phalaris arundinacea*), creeping foxtail (*Alopecurus arundinaceus*), streambank wheatgrass (*Agropyron riparium*) and tall fescue (*Festuca alatiior*).

Results showed that most tree seedlings were able to survive on sites 1 and 3 (Figs. GS-21-3 and -4), while they rapidly died on the untreated site 2 (Table GS-21-1). However, when peat was added on the top of the tailings or mixed with the



Figure GS-21-3: Seedlings growing on site 1 for two growing seasons.



Figure GS-21-4: Seedlings growing on site 3 for two growing seasons.

Table GS-21-1: Survival of seedlings planted on the tailings in July 2000 and June 2001. Measurements were done in September 2001.

Plant species (planted in 2000)	Survival (%)		
	Site 1	Site 2	Site 3
Jack pine	80	0	87
White spruce	83	0	100
Tamarack	100	0	100
Red-osier dogwood	93	0	80
Yellow willow	38	0	69
Bog birch	86	0	86
Plant species (planted in 2001)	Site 1	Site 2 (with peat)	
		Site 2	Site 3
Jack pine	55	87	95
White spruce	69	75	100
Red-osier dogwood	100	87	90
Yellow willow	69	50	92

tailings matter at site 2, the seedlings were still alive after three months (Table GS-21-1; Fig. GS-21-5). However, new root growth, a sensitive indicator of successful plant adaptation, was observed only on sites where the peat was not mixed with the heavy metal-rich tailings. Among the seedlings planted in 2000 at site 1, tamarack (Fig. GS-21-6) had the highest survival rate followed by red-osier dogwood, bog birch, white spruce, jack pine and willow (Table GS-21-1). Transpiration rates were measured in red-osier dogwood seedlings to estimate their level of stress (Fig. GS-21-7). Results indicated the importance of drainage conditions and sheltering effects of vegetation at the site, as well as the stress-inducing effect of very high metal contents in the soil.

Indian mustard and white mustard seeds germinated and survived in the field when peat was added on the top of the tailings (Table GS-21-2; Fig. GS-21-8). This is an important finding in light of the suitability of these species for phytoremediation and phytomining. Among the grass seeds tested, tall fescue, streambank wheatgrass and slender wheatgrass had the highest survival rates on the untreated sites (Table GS-21-2).

Several native plant species including manna grass (*Glyceria striata*) and horsetail (*Equisetum* sp.) were identified growing on the tailings. In addition, some fireweed (*Epilobium angustifolium*) plants were found growing on the tailings amended with peat. The metal-accumulating ability and suitability of these species for phytoremediation and phytomining purposes will be tested in future studies.

Greenhouse Study

Seeds of the following species were also planted in the greenhouse: Indian mustard (*Brassica juncea*), white mustard (*Sinapis alba*), slender wheatgrass (*Agropyron trachycaulum*), altai wildrye (*Elymus angustus*), reed canary grass (*Phalaris arundinacea*), creeping foxtail (*Alopecurus arundinaceus*), streambank wheatgrass (*Agropyron riparium*) and tall fescue (*Festuca alatiior*). Seeds were planted in trays on tailings collected from the top 15 cm of the three selected sites. The trays were sprayed with distilled water regularly to keep moisture level relatively constant. Seeds of the selected species were also planted on tailings mixed with peat at a ratio of one to one.



Figure GS-21-5: Seedlings growing on site 2 after peat addition.

Germination and survival rates of seeds planted in the greenhouse on the collected tailing material showed similar trends as the field experiments (Table GS-21-3). However, survival rates in the greenhouse were higher, indicating the important role of climatic factors, such as water supply.

Elemental Analyses of Plant Tissues

Table GS-21-4 shows the elemental analyses of plant tissues. The results of the analyses of plant shoots harvested at sites 1 and 3 after one growing season, both in the field and greenhouse, are promising in terms of high metal accumulation by selected plant species. Results from analyses of spruce and pine shoots growing in the field and in the greenhouse indicate a relatively high accumulation rate of gold. Willow seedlings seem to be tolerant to the large amounts of zinc they accumulated during one growing season (Table GS-21-4). Available data also suggest high accumulation rates of Ni, As and Se by all tested species. However, only a few species and a limited number of samples were tested and more detailed study is necessary before any conclusion can be made regarding plant ability to accumulate metals of interest.

FUTURE WORK

The focus of field experiments in the coming growing season will be the determination of the best combination of different amendments to the tailings surface layer to increase the long-term survival rate of selected plant species. Newly identified plant species native to the environment and species with traits induced by adaptation processes derived from seeds collected near tailings will be used for further study. Metal content in plants surviving two growing seasons will be measured to determine the most promising species for phytoremediation purposes. Furthermore, different soil treatment that would enhance the biomass growth of Indian mustard (*Brassica juncea*) – a promising plant species for bio-ore formation – will be investigated. The native fast-growing species, such as horsetail, manna grass and fireweed will be studied for their ability to form a cost-effective bio-ore.

ACKNOWLEDGMENTS

We would like to thank Jennifer Mustard, Mila and Tony Sailer for fieldwork assistance.



Figure GS-21-6: Tamarack growing on site 1 for two growing seasons.



Figure GS-21-7: Transpiration rate measurement at site 1.

Table GS-21-2: Survival of plants three months after seeding on tailings in the field.

Plant species	Survival (%)					
	Site 1	Site 2	Site 3	Site 1 (with peat)	Site 2 (with peat)	Site 3 (with peat)
Indian mustard	0	0	0	25	8	49
White mustard	0	0	0	49	6	65
Altai wildrye	26	0	16	n.a.	8	n.a.
Slender wheatgrass	44	0	38	n.a.	1	n.a.
Reed canary grass	n.a.	n.a.	27	n.a.	n.a.	n.a.
Creeping foxtail	0	n.a.	21	n.a.	n.a.	n.a.
Streambank wheatgrass	29	n.a.	47	n.a.	n.a.	n.a.
Tall fescue	n.a.	n.a.	50	n.a.	n.a.	n.a.

Note: n.a. - not available



Figure GS-21-8: Indian mustard seedling growing on site 3 for one growing season.

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Table GS-21-3: Survival of plants three months after seeding on tailings in the greenhouse.

Plant species	Survival (%)					
	Site 1	Site 2	Site 3	Site 1 (with peat)	Site 2 (with peat)	Site 3 (with peat)
Indian mustard	0	0	0	96	40	98
White mustard	0	0	0	100	50	98
Altai wildrye	96	0	67	n.a.	58	n.a.
Slender wheatgrass	89	0	40	n.a.	100	n.a.
Reed canary grass	38	n.a.	87	n.a.	n.a.	n.a.
Creeping foxtail	77	n.a.	88	n.a.	n.a.	n.a.
Streambank wheatgrass	94	n.a.	91	n.a.	n.a.	n.a.
Tall fescue	100	n.a.	100	n.a.	n.a.	n.a.

Note: n.a. - not available

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Table GS-21-4: Vegetation geochemical data for ashed samples collected from sites 1 and 3 at the study site and in the greenhouse. All values in ppm unless otherwise noted. A value of 999999 indicates a concentration greater than the range of the instrument. A negative value indicates a concentration less than the lower limit of determination.

Sample ID	Pre-ash wt (g)	Ash wt (g)	Ash (%)	Li	Be	B	Na (%)	Mg (%)	Al	Si	K (%)	Ca (%)	Sc	Ti	V	Cr	Mn	Fe (%)	Co	Ni
Plants growing in the field																				
D-site 1, planted	0.273	0.008	2.93	12	0.058	898	2.10	5.22	4,430	10,900	19.0	28.7	6.2	164	-6	-	1,330	1.92	67.0	131
S-site 1, wild	0.946	0.068	7.19	15.0	0.046	432	0.23	0.868	6,000	2,530	8.37	23.1	4.0	142	6.2	1.1	2,520	2.46	19.1	94.6
S-site 1, planted	0.54	0.038	7.04	15.3	0.032	262	0.46	4.29	4,020	3,780	12.7	16.9	3.9	129	-1	-1	2,980	1.60	25.2	35.7
A-site 1, wild	0.924	0.075	8.12	5.1	0.011	411	0.23	0.937	1,930	2,230	7.77	29.8	2.1	56	1.1	-0.7	379	0.965	56.8	41.1
W-site 1, planted	0.372	0.023	6.18	8	0.024	506	0.83	3.91	2,530	4,690	13.2	19.4	3.0	98	-2	-2	2,860	1.13	29.3	40.8
W-site 1, wild	0.330	0.026	7.88	1	0.010	464	0.50	0.654	1,210	2,840	7.30	37.8	1.8	42	6	8	376	0.707	41.2	72.7
D-site 3, planted	0.274	0.015	5.47	3	0.020	204	0.78	2.23	4,700	6,600	5.03	26.4	4.3	114	13	19	425	1.91	16.9	54.6
P-site 3, planted	0.969	0.038	3.92	16.9	0.024	169	0.54	3.18	9,270	4,510	13.6	7.96	5.5	143	17	23	1,430	3.18	35.5	62.9
W-site 3, planted	0.394	0.020	5.08	4	0.012	195	0.68	3.21	3,550	4,200	10.4	26.9	2.9	85	10	14	1,000	1.49	18.1	60.1
Plants growing in the greenhouse																				
D-site 1	1.157	0.039	3.37	9.6	0.006	438	0.44	1.08	616	1,940	11.5	36.5	1.3	27	16	23	192	0.316	2.76	32.9
D-site 1	0.961	0.030	3.12	22.9	0.006	730	0.49	1.39	412	2,030	15.0	33.0	1.1	29	28	38	122	0.299	2.35	26.9
D-site 1	1.222	0.0276	2.26	4.8	-0.002	142	0.04	0.314	32.9	300	1.9	6.31	0.3	5	2.8	4.0	39.1	0.059	0.644	6.03
D-site 1	0.960	0.035	3.65	17.8	0.004	504	0.55	1.25	271	1,830	13.9	31.9	1.3	22	21	29	108	0.266	2.30	29.6
Wildrye-site 1	1.012	0.071	7.02	44.2	0.006	768	0.82	2.26	664	3,080	999999	12.5	2.1	29	12.1	16.7	250	0.317	3.43	13.0
Slender Wheatgrass-site 1	0.786	0.068	8.65	16.9	0.008	814	0.35	1.18	1,050	2,900	15.8	14.6	2.1	35	6.9	9.5	236	0.509	6.00	21.7
P-site 1	0.698	0.030	4.30	95.6	0.010	3,030	1.05	3.04	1,250	3,260	23.1	20.6	1.8	65	16	23	1,410	0.571	8.94	37.1
S-site 1	0.191	0.006	3.14	109	0.013	2,430	2.08	2.85	1,990	7,610	26.9	26.0	3.3	84	102	152	1,360	0.664	10.0	75.4
D-site 3	1.031	0.037	3.59	1.0	0.002	269	0.25	1.42	196	1,310	13.2	30.4	1.0	23	23	33	196	0.272	2.08	31.5
D-site 3	0.957	0.036	3.76	1.2	0.004	290	0.33	1.31	171	1,280	11.4	33.5	1.0	26	27	37	200	0.277	2.01	27.4
D-site 3	0.996	0.045	4.52	1.4	0.006	280	0.31	1.86	294	1,460	14.4	29.6	1.1	33	21	31	280	0.303	2.51	25.8
D-site 3	1.009	0.029	2.87	2.2	0.007	375	0.54	1.42	279	2,180	14.9	31.6	1.2	35	30	42	269	0.260	2.24	43.9
Wildrye-site 3	1.030	0.064	6.21	5.3	0.011	92	1.14	1.43	999	2,440	999999	11.0	1.9	53	11.1	15.0	318	0.381	4.42	17.2
Slender Wheatgrass-site 3	0.896	0.070	7.81	3.5	0.010	105	0.47	0.869	1,400	2,360	21.4	14.0	1.8	49	6.6	8.6	328	0.655	6.52	17.6
P-site 3	0.725	0.024	3.31	10	0.011	359	0.88	2.15	1,530	3,340	18.9	21.6	1.8	76	20	29	1,860	0.664	5.68	35.2
S-site 3	0.099	0.002	2.02	24	0.06	616	4.2	3.90	3,310	16,200	30.3	44.1	8	172	351	503	3,110	0.95	10.2	168
Control material V7A				4.4	0.454	254	0.10	3.50	4,790	4,020	11.3	19.3	2.8	234	4.3	4.3	11,300	3.09	54.3	1,680
Standard reference data V7A +/-				4.6	0.52	198	0.10	4.07	5,125	553	10.1	21.2	2.3	362	8.3	10.5	10,077	1.46	48.8	1,451
				2.0	0.16	93	0.02	0.949	1,170	386	1.94	4.37	1.7	69	2.8	5.5	1,798	0.321	5.87	201

D-dogwood, S-white spruce, A-aspen, W-willow, P-jack pine

Table GS-21-4: Vegetation geochemical data for ashed samples collected from sites 1 and 3 at the study site and in the greenhouse. All values in ppm unless otherwise noted. A value of 999999 indicates a concentration greater than the range of the instrument. A negative value indicates a concentration less than the lower limit of determination. (continued)

Sample ID	Cu	Zn	Ge	Ge	As	Se	Rb	Sr	Y	Zr	Nb	Mo	Pd	Ag	Cd	In	Sn	Sb	Te	Cs
Plants growing in the field																				
D-site 1, planted	8,270	620	0.602	-0.006	76	-6	53.6	755	9.93	28.4	0.784	8.00	-19	26.2	3.38	132	-6	0.416	15.7	0.267
S-site 1, wild	8,430	501	2.30	0.172	11.7	24.6	20.0	565	9.03	4.78	0.917	4.18	57	9.75	1.89	131	2	0.476	19.9	0.236
S-site 1, planted	5,910	938	1.75	0.060	5	5	78.3	781	6.29	6.70	0.695	11.0	103	9.62	1.51	83.2	-1	0.336	13.9	0.339
A-site 1, wild	3,820	693	0.689	0.084	16.8	57.7	13.3	193	1.62	4.75	0.797	2.77	57	3.22	15.2	33.7	-1	0.223	6.43	0.058
W-site 1, planted	2,900	1,570	0.815	-0.002	4	8	43.2	391	3.91	13.1	0.509	3.11	-7	9.40	20.1	58.6	-2	0.355	8.79	0.230
W-site 1, wild	1,330	1,780	0.093	-0.002	28	103	5.71	189	1.80	12.8	0.954	2.84	-6	5.65	57.0	25.4	-2	0.140	4.37	0.049
D-site 3, planted	1,780	426	0.800	-0.003	17	69	16.1	436	1.37	13.9	0.712	6.53	-10	15.6	1.86	58.2	-3	0.249	8.34	0.152
P-site 3, planted	3,700	421	2.50	0.438	5	17	34.3	118	2.31	5.62	0.731	6.38	91	9.55	4.34	116	-1	0.283	8.94	0.395
W-site 3, planted	1,500	980	0.814	-0.003	17	77	74.9	397	1.13	12.0	0.738	4.00	-8	8.38	22.0	44.8	-3	0.193	6.50	0.300
Plants growing in the greenhouse																				
D-site 1	200	281	0.512	0.366	41	140	15.7	313	0.164	7.27	1.08	2.53	95	5.05	0.445	9.43	-1	0.103	3.46	0.073
D-site 1	155	245	0.143	0.114	49	172	14.4	255	0.127	6.32	0.898	2.35	-5	3.71	0.518	4.15	-2	0.131	3.01	0.044
D-site 1	45.6	46.3	0.067	0.061	7.6	27.2	2.82	37.3	0.006	0.700	0.084	0.303	11	-0.04	0.146	3.04	-2	0.018	0.507	0.010
D-site 1	169	305	0.364	0.373	42	142	15.1	264	0.124	10.7	0.899	2.79	128	5.73	0.562	7.69	-1	0.234	2.56	0.036
Wildrye-site 1	519	388	0.481	0.466	19.2	68.1	43.2	290	0.315	7.38	0.412	2.90	78	1.41	7.36	15.4	-1	0.157	4.25	0.061
Slender Wheatgrass-site 1	733	320	0.434	0.268	15.2	51.1	17.6	179	0.526	3.97	0.421	7.17	47	3.43	3.81	15.1	-1	0.154	4.71	0.041
P-site 1	871	1,180	0.471	-0.002	26	97	31.4	136	0.478	18.7	0.616	10.2	68	7.37	9.84	15.8	-2	0.275	3.74	0.051
S-site 1	1,280	798	0.361	-0.008	79	302	38.8	844	0.875	59.6	0.499	17.9	-25	28.5	3.29	28.6	-8	0.405	11.3	0.073
D-site 3	137	363	0.482	0.650	40	141	18.8	278	0.094	7.33	0.936	4.73	90	3.25	0.324	6.31	-1	0.077	3.24	0.049
D-site 3	116	176	0.513	0.640	48	179	23.4	355	0.078	8.90	1.05	5.64	111	4.10	0.352	6.49	-1	0.098	3.54	0.081
D-site 3	222	265	0.495	0.444	40	146	21.4	251	0.186	7.31	0.915	6.35	86	3.83	0.317	8.16	-1	0.107	3.47	0.093
D-site 3	181	437	0.165	0.146	47	158	18.3	269	0.117	11.3	0.890	4.71	-5	3.23	0.618	1.10	-2	0.095	3.00	0.062
Wildrye-site 3	702	276	0.647	0.500	16.8	61.2	67.7	135	0.731	9.42	0.426	7.74	133	2.90	3.54	20.8	-1	0.148	5.00	0.152
Slender Wheatgrass-site 3	967	259	0.652	0.298	14.1	51.9	37.1	115	0.901	7.08	0.456	14.2	94	2.93	2.47	21.3	-1	0.157	7.91	0.140
P-site 3	1,230	583	0.548	-0.002	28	110	39.9	118	0.808	21.5	0.638	45.0	98	5.80	5.86	22.5	-2	0.277	7.48	0.115
S-site 3	995	1,090	1.95	-0.03	264	945	59.9	965	1.50	157	0.78	192	-75	72.8	3.8	57.7	-25	13.2	23.1	0.12
Control material V7A	457	2,340	3.23	0.586	9.6	29.4	435	1,860	4.71	1.58	1.42	2.17	85	1.79	1.62	14.6	2	0.590	0.762	1.30
Standard reference data V7A +/-	304	1,708	2.70	0.143	11.9	39.9	421	1,735	4.86	0.488	0.600	1.52	82	1.81	1.50	14.9	-1	0.240	1.26	1.39
	68	368	1.22	0.116	4.00	14.4	74.3	304	0.393	0.436	0.074	0.143	15	0.09	0.189	2.12	-	0.044	0.459	0.111

D-dogwood, S-white spruce, A-aspen, W-willow, P-jack pine

Table GS-21-4: Vegetation geochemical data for ashed samples collected from sites 1 and 3 at the study site and in the greenhouse. All values in ppm unless otherwise noted. A value of 999999 indicates a concentration greater than the range of the instrument. A negative value indicates a concentration less than the lower limit of determination. (continued)

Sample ID	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Re (ppt)
Plants growing in the field																			
D-site 1, planted	841	19.3	97.2	6.41	26.5	5.44	1.22	5.07	0.595	2.56	0.419	1.04	0.119	0.807	0.174	0.651	0.007	-0.6	26,600
S-site 1, wild	139	17.7	42.1	5.08	21.6	4.20	0.878	4.10	0.485	2.08	0.346	0.867	0.093	0.599	0.110	0.175	0.008	1.0	44,200
S-site 1, planted	860	10.1	32.7	2.99	12.7	2.55	0.665	2.71	0.308	1.39	0.234	0.607	0.077	0.655	0.169	0.182	0.007	0.7	10,100
A-site 1, wild	77.8	1.90	9.41	0.482	2.02	0.398	0.103	0.483	0.061	0.288	0.052	0.143	0.019	0.146	0.036	0.120	0.002	0.4	23,500
W-site 1, planted	418	7.50	41.4	2.16	8.71	1.74	0.397	1.78	0.195	0.854	0.143	0.360	0.042	0.309	0.075	0.290	0.003	0.4	14,100
W-site 1, wild	244	3.54	33.4	1.07	4.29	0.856	0.198	0.993	0.097	0.419	0.069	0.182	0.022	0.177	0.057	0.304	-0.002	-0.2	11,200
D-site 3, planted	468	0.754	33.9	0.273	0.815	0.184	0.109	0.426	0.042	0.233	0.048	0.139	0.023	0.204	0.065	0.290	-0.003	0.5	12,900
P-site 3, planted	198	0.983	12.9	0.292	1.19	0.290	0.106	0.474	0.064	0.399	0.080	0.232	0.035	0.272	0.062	0.124	0.002	2.1	17,700
W-site 3, planted	415	0.815	30.9	0.279	0.824	0.186	0.092	0.406	0.037	0.197	0.037	0.113	0.017	0.179	0.058	0.246	-0.003	0.6	2,970
Plants growing in the greenhouse																			
D-site 1	222	0.298	15.8	0.113	0.259	0.055	0.042	0.207	0.011	0.040	0.006	0.018	0.004	0.087	0.042	0.156	-0.001	0.3	12,300
D-site 1	165	0.170	11.8	0.067	0.164	0.038	0.034	0.155	0.008	0.024	0.004	0.012	0.003	0.055	0.026	0.140	-0.002	-0.2	6,350
D-site 1	19.1	0.021	1.60	0.011	0.027	0.005	0.003	0.021	-0.002	0.003	-0.002	0.002	-0.002	0.008	0.004	0.017	-0.002	-0.2	-2
D-site 1	297	0.161	24.3	0.109	0.157	0.032	0.050	0.294	0.010	0.024	0.004	0.011	0.005	0.097	0.051	0.216	0.002	0.4	5,560
Wildrye-site 1	349	0.290	17.6	0.116	0.291	0.060	0.063	0.230	0.014	0.053	0.011	0.032	0.009	0.141	0.059	0.169	0.002	0.3	255,000
Slender Wheatgrass-site 1	270	0.417	12.6	0.135	0.430	0.102	0.057	0.223	0.019	0.082	0.017	0.048	0.010	0.129	0.046	0.085	0.001	0.3	179,000
P-site 1	564	0.712	69.2	0.354	0.675	0.134	0.106	0.698	0.030	0.089	0.017	0.050	0.012	0.203	0.099	0.436	-0.002	-0.2	190,000
S-site 1	1,290	0.883	141	0.606	0.846	0.189	0.176	1.08	0.044	0.152	0.028	0.084	0.020	0.319	0.150	1.35	-0.008	-0.8	186,000
D-site 3	224	0.122	15.3	0.069	0.104	0.025	0.039	0.194	0.007	0.014	0.003	0.008	0.004	0.086	0.038	0.154	0.002	0.5	7,660
D-site 3	280	0.114	18.8	0.077	0.086	0.019	0.047	0.228	0.007	0.013	0.003	0.007	0.004	0.103	0.050	0.182	0.002	0.3	4,790
D-site 3	216	0.215	15.6	0.087	0.185	0.040	0.041	0.204	0.009	0.031	0.006	0.019	0.005	0.094	0.041	0.156	0.001	0.3	10,700
D-site 3	384	0.151	29.3	0.120	0.134	0.025	0.064	0.314	0.010	0.017	0.003	0.012	0.005	0.120	0.058	0.248	-0.002	-0.2	9,720
Wildrye-site 3	513	0.660	30.4	0.251	0.687	0.150	0.109	0.464	0.030	0.124	0.024	0.069	0.016	0.241	0.094	0.213	0.003	0.4	498,000
Slender Wheatgrass-site 3	388	0.876	18.9	0.270	0.969	0.198	0.100	0.397	0.036	0.162	0.030	0.087	0.016	0.207	0.073	0.170	0.002	0.5	447,000
P-site 3	522	0.968	66.3	0.408	1.01	0.204	0.110	0.642	0.038	0.145	0.027	0.079	0.015	0.191	0.084	0.475	-0.002	0.3	463,000
S-site 3	2,690	2.02	320	1.34	1.96	0.40	0.37	2.68	0.09	0.26	0.04	0.14	0.04	0.69	0.37	3.54	-0.03	3	593,000
Control material V7A	242	24.2	28.5	2.51	7.57	1.05	0.248	1.31	0.149	0.693	0.124	0.330	0.039	0.282	0.042	0.046	0.024	0.2	6,660
Standard reference data V7A +/-	423 467	25.8 3.81	30.3 6.94	2.64 0.189	7.96 0.541	1.20 0.101	0.295 0.051	1.48 0.196	0.161 0.014	0.712 0.052	0.127 0.010	0.348 0.028	0.039 0.003	0.228 0.020	0.033 0.004	0.026 0.018	0.007 0.006	0.3 0.1	7,650 901

D-dogwood, S-white spruce, A-aspen, W-willow, P-jack pine

Table GS-21-4: Vegetation geochemical data for ashed samples collected from sites 1 and 3 at the study site and in the greenhouse. All values in ppm unless otherwise noted. A value of 999999 indicates a concentration greater than the range of the instrument. A negative value indicates a concentration less than the lower limit of determination. (continued)

Sample ID	Pt (ppb)	Au (ppb)	Ti	Pb	Bi	Th	U
Plants growing in the field							
D-site 1, planted	-13	642	0.277	29.4	39.7	0.454	0.374
S-site 1, wild	9	971	0.276	29.3	46.0	0.450	0.336
S-site 1, planted	5	310	0.349	18.1	27.9	0.353	0.657
A-site 1, wild	4	484	0.161	10.1	13.5	0.154	0.387
W-site 1, planted	-4	343	0.123	10.7	23.3	0.229	0.116
W-site 1, wild	-4	174	0.009	7.01	8.66	0.125	0.065
D-site 3, planted	-7	91	0.082	32.1	32.4	0.095	0.095
P-site 3, planted	8	123	0.412	44.1	44.8	0.137	0.077
W-site 3, planted	-5	93	0.125	26.9	21.4	0.122	0.162
Plants growing in the greenhouse							
D-site 1	5	141	0.020	2.68	1.13	0.060	0.033
D-site 1	-3	65	0.031	3.28	1.43	0.036	0.020
D-site 1	-4	8	0.005	0.32	0.08	0.004	0.006
D-site 1	4	125	0.057	8.23	1.12	0.034	0.030
Wildrye-site 1	3	50	0.035	4.92	5.00	0.056	0.127
Slender Wheatgrass-site 1	-2	123	0.031	5.05	6.07	0.095	0.274
P-site 1	5	253	0.038	8.79	7.48	0.088	0.220
S-site 1	-17	1,580	0.073	16.9	14.7	0.139	0.414
D-site 3	-3	-3	0.041	4.27	0.80	0.026	0.016
D-site 3	4	4	0.024	3.13	0.55	0.022	0.058
D-site 3	5	6	0.034	4.22	1.51	0.047	0.090
D-site 3	-3	5	0.068	4.37	0.88	0.026	0.027
Wildrye-site 3	3	30	0.056	14.5	6.13	0.156	0.277
Slender Wheatgrass-site 3	-2	34	0.066	17.5	8.11	0.218	0.353
P-site 3	-4	122	0.089	23.4	10.2	0.176	0.186
S-site 3	70	232	0.31	224	23.1	0.37	0.40
Control material V7A	44	8	0.023	23.0	0.06	0.517	0.411
Standard reference data V7A	40	11	0.023	22.9	0.18	0.522	0.394
+/-	16	8	0.009	2.1	0.14	0.048	0.031

D-dogwood, S-white spruce, A-aspen, W-willow, P-jack pine

Conley, G.G. 2001: Manitoba Stratigraphic Database and the Capital Region Study, 2001; *In* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 150-151.

SUMMARY

In 1999, preliminary maps (bedrock potential, overburden thickness, geology, bedrock topography [5 m contour interval]) for the northern portion of the Capital Region Study were released in printed form (Bezys et. al., 1999a-h). The mapping of the southern portion of the study area has been completed and the maps and report are in the final editing stage for the entire Capital Region.

The Manitoba Stratigraphic Database (MSD) continues to be updated. It contains 5619 stratigraphic, mineral exploration, oil and gas, and other wells, of which 4340 wells have formation tops.



MANITOBA STRATIGRAPHIC DATABASE AND THE CAPITAL REGION STUDY

Sixteen 1:50 000 map sheets for the Capital Region Study are currently undergoing final editing. The map sheets include Selkirk (62I/2), Stonewall (62I/3), Teulon (62I/6), Netley Marsh (62I/7), Ste. Anne (62H/10), St. Adolphe, (62H/11), Winnipeg (62H/14) and Dugald (62H/15). The maps will show overburden thickness (5 m contour interval) and bedrock topography on a colour bedrock geology base. These maps will supersede the previous black and white editions, which are now mostly out of print. The maps and report are in the production stage and are expected to be released in early 2002. The map titles are:

- CAP-1 Geology, Overburden Thickness and Bedrock Potential, Selkirk (NTS 62I/2)
- CAP-2 Geology and Bedrock Topography, Selkirk (NTS 62I/2)
- CAP-3 Geology, Overburden Thickness and Bedrock Potential, Stonewall (NTS 62I/3)
- CAP-4 Geology and Bedrock Topography, Stonewall (NTS 62I/3)
- CAP-5 Geology, Overburden Thickness and Bedrock Potential, Teulon (NTS 62I/6)
- CAP-6 Geology and Bedrock Topography, Teulon (NTS 62I/6)
- CAP-7 Geology, Overburden Thickness and Bedrock Potential, Netley Marsh (NTS 62I/7)
- CAP-8 Geology and Bedrock Topography, Netley Marsh (NTS 62I/7)
- CAP-9 Geology, Overburden Thickness and Bedrock Potential, Ste. Anne (NTS 62H/10)
- CAP-10 Geology and Bedrock Topography, Ste. Anne (NTS 62H/10)
- CAP-11 Geology, Overburden Thickness and Bedrock Potential, St. Adolphe (NTS 62H/11)
- CAP-12 Geology and Bedrock Topography, St. Adolphe (NTS 62H/11)
- CAP-13 Geology, Overburden Thickness and Bedrock Potential, Winnipeg (NTS 62H/14)
- CAP-14 Geology and Bedrock Topography, Winnipeg (NTS 62H/14)
- CAP-15 Geology, Overburden Thickness and Bedrock Potential, Dugald (NTS 62H/15)
- CAP-16 Geology and Bedrock Topography, Dugald (NTS 62H/15)

Data sources for the maps include 5897 water wells and 182 stratigraphic wells from MSD. Despite much detailed editing and cleaning of the data, with respect to borehole elevations and quality of the water well data, the final bedrock surface appeared quite 'bumpy'. The 'bumpy' surface gives an impression of detail that is probably the result of minor errors rather than actual bedrock detail. To smooth the bumps, a moving average surface was created by QuickSURF™ (version 5.1), used within AutoCAD® Release13. The moving average routine acts as an averaging filter resulting in a smoother surface. The final contours for both overburden thickness and bedrock surface were created from the moving average surface.

The generation of new bedrock contours required that the geological formation boundaries be modified to accommodate the new zones of outcrop. Editing of the formation boundaries was completed by J. Bamburak. Quarries and outcrop locations were also brought up to date. Bedrock potential is considered where overburden thickness is less than 5 m.

MANITOBA STRATIGRAPHIC DATABASE: AN UPDATE

The Manitoba Stratigraphic Database continues to be updated. However, this has proceeded slower than expected due to the amount of time required by the Capital Region Study and other projects. At this time, formation tops exist in 4340 stratigraphic, mineral exploration, oil and gas, and other wells.

A set of nine insert maps has been produced for the upcoming NTS 63G sheet of the Bedrock Geology Compilation Map Series. These insert maps include isopach maps for the Winnipeg, Red River, Stony Mountain and Stonewall formations and the Interlake Group. Precambrian structure, depth to Precambrian, depth to bedrock and bedrock topography and outcrop belt maps have also been produced. The NTS 63G Bedrock Geology Compilation Map sheet will be released in early 2002.

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GS-23 CONSTRUCTION OF A THREE-DIMENSIONAL GEOLOGICAL MODEL FOR THE SOUTHERN MANITOBA PHANEROZOIC TERRANE

by G.L.D. Matile, L.H. Thorleifson¹, J.D. Bamburak, R.K. Bezys, M.P.B. Nicolas, G.G. Conley, G.R. Keller, and M. Pyne¹



Matile, G.L.D., Thorleifson, L.H., Bamburak, J.D., Bezys, R.K., Nicolas, M.P.B., Conley, G.G., Keller, G.R. and Pyne, M. 2001: Construction of a three-dimensional geological model for the southern Manitoba Phanerozoic terrane; *In* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 152-155.

SUMMARY

Nearly all of the one million inhabitants of Manitoba live in the 400 by 700 km area of Phanerozoic terrane in the southern portion of the province. The majority live in the Winnipeg area, a 200 by 230 km area in the southeastern corner of the province. Winnipeg obtains water from Shoal Lake, but the 200 000 residents of surrounding areas rely on groundwater obtained from bedrock aquifers. Fresh water in these aquifers consists of modern recharge and relict subglacial recharge, but a saline-water system recharged in South Dakota and Montana discharges to the western Red River valley. Research on the long-term sustainability of the fresh groundwater resource is addressing the protection of recharge, and ensuring that excessive pumping does not lead to unacceptable lateral migration of the saline waters. Three-dimensional (3-D) modelling is a key element of this strategy, and a geological model is required. The 3-D model will have many applications, from basic science to groundwater-flow modelling and livestock management.

The intention is to construct a 3-D geological model for the Phanerozoic terrane of southern Manitoba, south of latitude 55°N and west of longitude 95°W. The Phanerozoic sequence, comprising Quaternary sediments and Phanerozoic sedimentary rocks, down to and including the Precambrian surface will be modelled. This will require the acquisition of all readily available, nonconfidential drillhole databases in a format that can easily be utilized in a geographic information system (GIS).

CONSTRUCTION OF A THREE-DIMENSIONAL GEOLOGICAL MODEL

Construction of a three-dimensional (3-D) model for the southern Manitoba Phanerozoic terrane requires progress in three major areas: 1) digitizing of maps required for the Manitoba Surficial Geology seamless 1:250 000 scale map compilation; 2) surficial mapping of areas that have not previously been mapped at a sufficient scale, and 3) 3-D mapping of all stratigraphic units.

Digitizing of Maps Required for the Manitoba Surficial Geology Seamless 1:250 000 Scale Map Compilation

There are 54 NTS map sheets in the province. Sources of published surficial geology maps are the Manitoba Mines Branch, the Geological Survey of Canada (GSC) and digital maps (GSC and joint GSC-MGS). Portions of four NTS 1:250 000 scale map sheets (approximately six half sheets) require original mapping.

To date, all Manitoba government surficial geological maps required for the seamless 1:250 000 compilations have been digitized (covering portions of five 1:250 000 scale map sheets). Seven GSC 1:250 000 scale maps have been digitized. This covers much of the farmland in Manitoba, but leaves another five GSC 1:250 000 scale maps still to be digitized. Approximately five and a half NTS 1:250 000 scale map sheets are already in digital format; these maps are all at 1:100 000 scale and will require some degree of simplification. Automated procedures are being developed to simplify 1:100 000 scale polygons to achieve a level of detail appropriate for both 1:1 000 000 scale and 1:250 000 scale compilations.

All digitized maps will require edge matching. There are blocks of map sheets, particularly in the north, that have been mapped by a single GSC geologist and will hopefully require little or no edge matching. However, at the other end of the spectrum, some areas will require field checking and possibly supplemental mapping.

In addition to edge matching, the individual map sheets will have to conform to a standardized terminology. Every legend item has been parsed into a standard set of descriptors (i.e., a data model), which includes variables such as genesis, lithology and morphology. When the resultant database, which contains the parsed legend items, is combined with the digitized map polygons, the result will be a digital map that can be queried and displayed, based on a number of different criteria that depend on user requirements.

Surficial Mapping (NTS 52M, 62J, 62O and 62P)

Portions of NTS 52M (Carroll Lake), 62J (Neepawa), 62O (Dauphin Lake) and 62P (Hecla) require new surficial geological mapping. This area was mapped by Johnston (1931) at a scale of 1:506 880, but this is not a sufficient level of detail. The northeastern half of 62O has been mapped by Nielsen and Matile (1985), and minor portions of 52M and 62P have been mapped by Groom (1985), Henderson and Way Nee (1998), and Henderson and Zdanowicz (1998). This leaves an area roughly equivalent to three NTS 1:250 000 scale map sheets that requires new mapping. The portion of this area lying west of Lake

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Winnipeg could, in the short term, be filled with digital soils polygons that have recently been made available by Agriculture and Agri-Food Canada.

Three-Dimensional Modelling

A 3-D model for the sedimentary rocks of southern Manitoba, including important aquifers, was completed as a series of paper contour maps more than a decade ago. This information has been computerized, but enhancement of the model, using data collected since the time of the original compilation, will be required. Much more effort will, however, be required to complete 3-D mapping of the sediments. A pilot for this activity in the Winnipeg area has been partially completed, and a presentation of the methods and partial model at a 3-D mapping workshop in Illinois in April 2001 met with a favourable response (Fig. GS-23-1). A refined method to complete the remainder of populated areas of the province where subsurface information is available from drillhole databases is now in development. The pilot Winnipeg-area model will be complete in November 2001. Whereas the model of the sediments is complete, including the south basin of Lake Winnipeg, work remains to be done on the sedimentary rocks.

For the rest of southern Manitoba, the complete 3-D model of the sediments and sedimentary rocks will cover the area south of latitude 55°N and west of longitude 95°W. In order to plan completion of this 3-D model, this area has been divided into six 200 km wide regions, each measuring 2° of latitude by 3° of longitude. Completion of the pilot has taken more than 3 years, but the subsequent five phases will benefit from province-wide database preparation done in association with the pilot and the fact that the methods and experience are now in place. The current estimate is that 6 months of effort by an experienced geologist will be required for each of the remaining five regions. There will, however, be constraints associated with

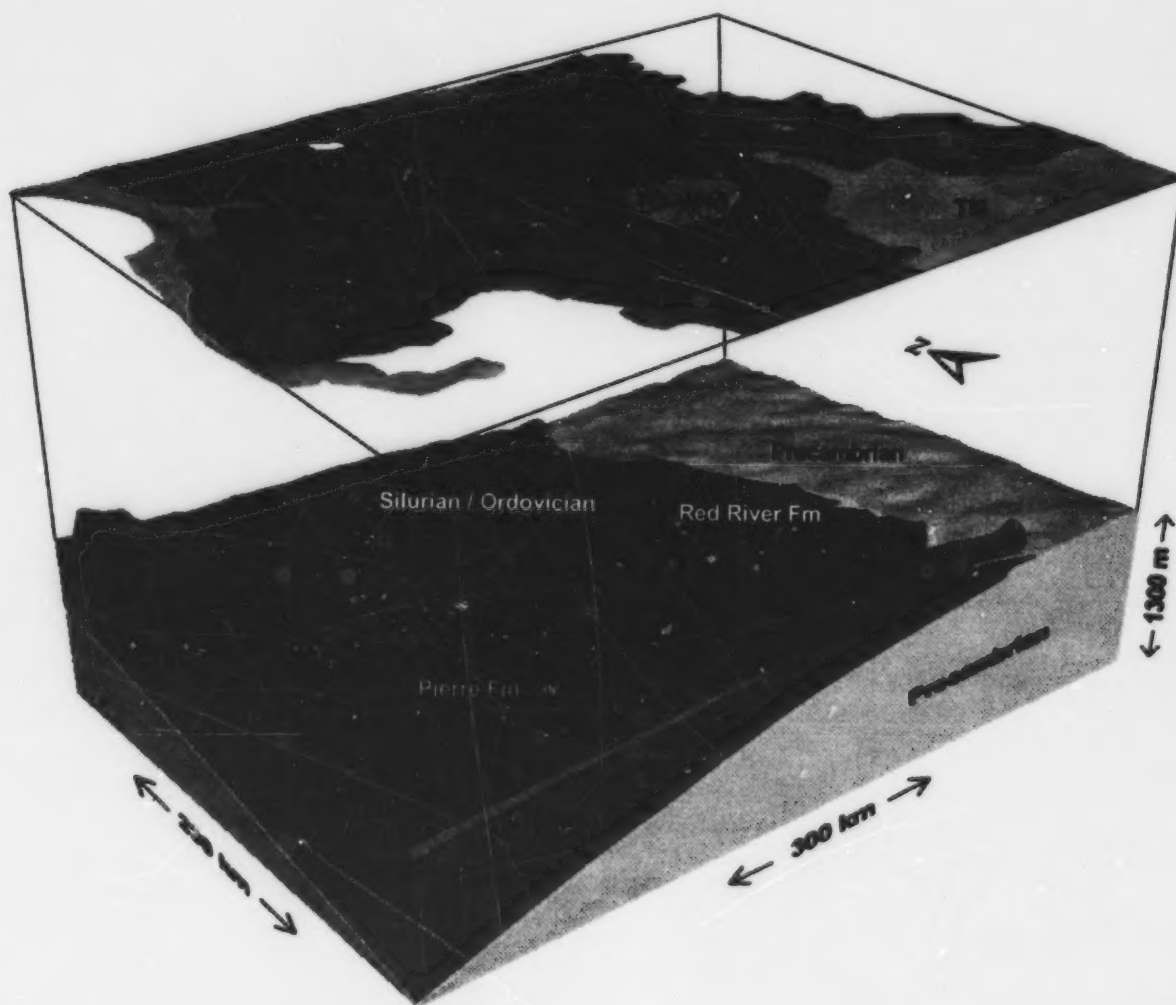


Figure GS-23-1: Simplified version of the 3-D model, covering an area from the Ontario border to approximately Brandon. This version of the model was developed for a groundwater-flow modelling thesis at the University of Manitoba. Quaternary sediments have been lifted off to show the rock surface.

unfamiliar geology, fewer wells and ambiguity in distinguishing shale and clay in southwestern Manitoba, and computing limitations as the study area increases in size. Construction of the complete model calls for full processing of multiple databases. The sedimentary rock data will be processed in the same manner as the data from water wells and coring that is being used for the sediments. The drillhole data will be linked to plan-view map data, using map-extent polygons that have been layered. Previously compiled elevation data for each sedimentary rock unit will be compared with the new data to determine extent of required revision.

The 3-D model is constructed using the following datasets (these datasets have generally been compiled for the entire region south of latitude 55°N):

Topography

Readily available topographic models have proven to be inadequate, so a new digital elevation model (DEM) was constructed from rectification data for digital orthophotography. Because the entire area was not covered by digital orthophotos, a surround for this data was compiled from topographic map contours and DEMs from neighboring jurisdictions. The resulting model has a grid resolution of 100 m, absolute vertical accuracy of about ± 3 m and relative accuracy of less than a metre. The data have been used to position drillholes vertically, so the geological model hangs from the topography. The model has provided insight into previously unrecognized geological features.

Bathymetry

Large lakes occur in the area, including Lake Winnipeg. These are key features in the hydrogeological landscape, and lake-bottom features provide insights into geology. Soundings from 22 hydrographic charts were therefore digitized and a database containing 31 607 digitized bathymetry points was created. These were modelled with shoreline data and locations of shoals, at a grid resolution of 100 m.

Surficial geology

Subsurface modelling is guided by the most detailed available surficial geological mapping. At this stage, the subsurface model is not linked to the polygons, due to the much greater detail of the surficial geological mapping relative to the resolution that could be achieved in the subsurface.

Quaternary stratigraphy

Key inputs to the 3-D model of the sediments were cored holes logged by geologists, and geophysical surveys. These high-quality results were extrapolated laterally using water-well data from 80 000 sites (obtained from GWDriII, the water-well database maintained by the Water Branch of Manitoba Conservation). Much effort was required to parse the 75 000 unique lithological descriptions in this database. Also, before this database could be used in a GIS environment, x-y coordinates were assigned using quarter-section centroids and elevations from the DEM. The 200 by 230 km Winnipeg region NATMAP area (the pilot area) was divided into 46 transects, each 5 km wide, and a large colour chart was printed for each transect, showing all drillhole data, surficial geology and surface elevations. The drillhole data, colour-coded for lithology, were interpreted as a series of vertical maps using the same methods used to compile plan-view maps. The interpretation was captured as a set of virtual drillholes at 5 km spacing, and individual units were gridded using MapInfo and Gemcom.

Sub-bottom seismic data from Lake Winnipeg have been utilized much like a series of drillholes. The south basin has been modelled and the north basin will be modelled during subsequent modelling phases. Not only will this provide us with a better understanding of the Quaternary geology of the area, both onshore and offshore, but it will better define the Paleozoic limit within the lake.

Bedrock geology

A new set of 1:1 000 000 scale bedrock polygons for the Phanerozoic units was constructed, linking outcrop to subcrop, to produce stacked polygons. Structure contours, from the Stratigraphic Map Series, for each Phanerozoic unit were gridded and these grids clipped with the set of stacked polygons.

The plan is to update this model and, in so doing, provide an audit on the Phanerozoic stratigraphic databases. Presently, three of four databases containing Phanerozoic stratigraphy have been reformatted to be used in a GIS environment. They are the Manitoba Stratigraphic Database (MSD), the Manitoba Oil and Gas Well Information System (MOGWIS) and the Western Canada Sedimentary Basin database (WCSB). The fourth database, which is being called Index Cards, should be ready shortly. Some additional rock information will be gleaned from GWDriII. All of these data will be plotted on transects and handled much like the Quaternary stratigraphic data.

Once completed, the 3-D model will provide a repository of all readily available nonconfidential drillhole data for the area. As such, the model will provide an ideal means of deriving drilling targets for the MSD, which is an ongoing program.

In addition, data-poor areas in Quaternary sediments, Phanerozoic sedimentary rocks or Precambrian igneous rocks will be easily recognized, thus providing targets for future drilling. Capturing the 3-D model at 5 km spacing is likely too coarse for some applications, but is manageable at the current staffing level and with available computing power. In the future, we may want to consider refining the model to 2.5 or even 1 km spacing.

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GS-24 SOLUTION-COLLAPSE BRECCIA OF THE UPPER DEVONIAN SAGEMACE MEMBER, SOURIS RIVER FORMATION, WINNIPEGOSIS AREA: PROGRESS REPORT

by L. Friedrich¹ and N. Chow¹

Friedrich, L. and Chow, N. 2001: Solution-collapse breccia of the Upper Devonian Sagemace Member, Souris River Formation, Winnipegosis area: progress report; in Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 156-158.



INTRODUCTION

The Devonian succession in Manitoba is characterized by three large-scale carbonate-evaporite cycles (Norris et al., 1982; Fig. GS-24-1). The oldest, thickest and best-defined depositional cycle comprises the Elk Point Group, which includes the Prairie Evaporite. The second cycle comprises the Dawson Bay Formation, which is topped by the Hubbard Evaporite, and the youngest cycle comprises the Souris River Formation, which includes the Sagemace and Point Wilkins members and the Davidson Evaporite. Dissolution of the evaporite units has resulted in the collapse of post-evaporite strata into voids, creating single- or multiple-event, salt-collapse structures (Bezys and McCabe, 1996). Uniform collapse of strata has produced no obvious structural deformation, whereas catastrophic collapse has formed a chaotic megabreccia.

Similar salt-collapse features have been identified in bedrock quarries near Winnipegosis. Quarry faces expose the Upper Devonian Sagemace Member of the Souris River Formation. These collapse features have been interpreted as solution-collapse breccia units (Bezys and McCabe, 1996). However, no extensive work has been done in this area to determine the origin and timing of these breccia units.

STUDY AREA

The two crushed stone quarries being studied for this project are located in the northeast quadrant of sec. 9, twp. 31, rge. 18, W 1st mer., 1.6 km north of the town of Winnipegosis, immediately south of Highway 20 (Fig. GS-24-2). Quarry walls of up to 5 m expose the Devonian Sagemace Member of the Souris River Formation. The walls show 1) buff to pink and purple, medium- to thick-bedded, fine-grained limestone, which is locally fossiliferous and burrow mottled, and (2) dark pink to yellow, poorly consolidated breccia of limited lateral extent.

OBJECTIVES

The primary objectives of this research are to interpret the depositional origin of the Sagemace Member and to determine the timing and origin of the breccia units in the Winnipegosis quarries. This work will involve 1) characterizing lithofacies in the two quarries and in cores from the quarries and adjacent areas, 2) describing the texture and composition of the breccia units, 3) determining the mineralogy and elemental geochemistry of the fine-grained breccia matrix, and 4) examining the stratigraphy of underlying Devonian strata.

METHODOLOGY

Fieldwork was completed during one week in July 2001. Detailed geologic maps were created of both the eastern and western Winnipegosis quarries by pace and compass (eastern quarry shown in Fig. GS-24-3), five stratigraphic sections were described and measured, and preliminary detailed lithofacies descriptions were documented. Representative samples were collected and key features were recorded photographically. Four coreholes (M-06-80, M-10-81, M-16-81 and M-5-2000), drilled by Manitoba Industry, Trade and Mines in the area of the Winnipegosis quarries, were logged and sampled in August 2001.

Thin sections are being made from the samples and will be stained with Alizarin Red S and potassium ferricyanide for

GROUP / FORMATION / MEMBER		Thickness (m)
DEVONIAN	SOURIS RIVER FORMATION	Sagemace Member
		20+
		basal shale
		2-14
		Davidson Evap. (dissolved)
	Point Wilkins Member	33-46
		First Red Beds
		3-14
	DAWSON BAY FORMATION	Hubbard Evap. (dissolved)
		26-60
		Second Red Beds
ELK POINT GROUP	Prairie Evaporite (partly dissolved)	0-129
		45-110
	WINNIPEGOSIS FORMATION	10-20
		Elm Point Fm.
ASHERN FORMATION		3-18

Figure GS-24-1: Generalized stratigraphic section of the Devonian succession in the Manitoba outcrop belt (modified from Norris et al., 1982).

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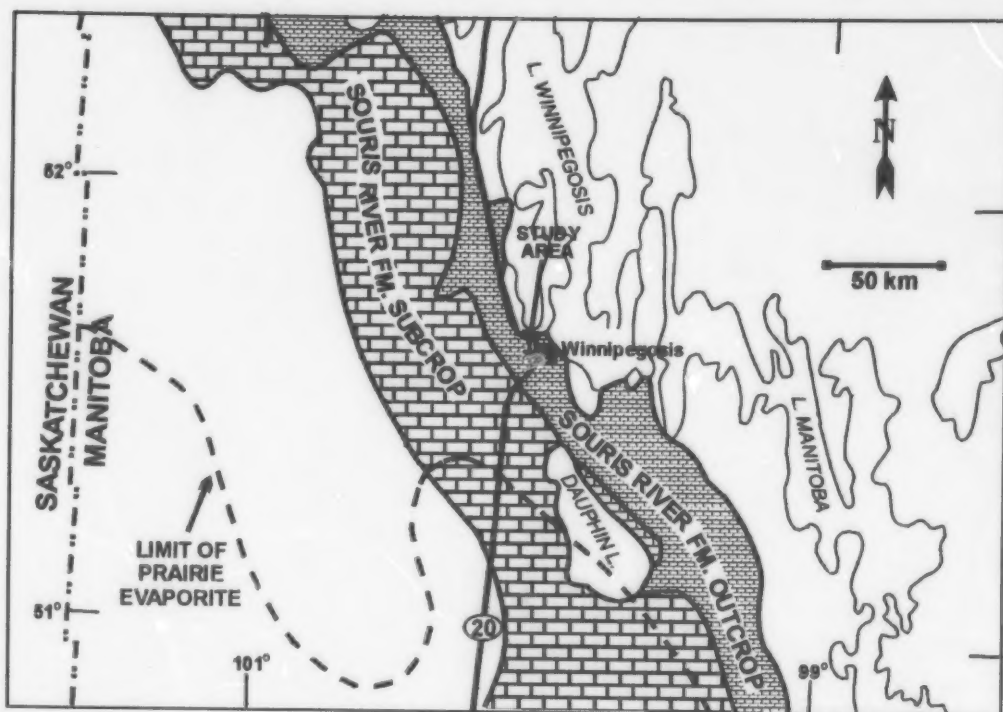
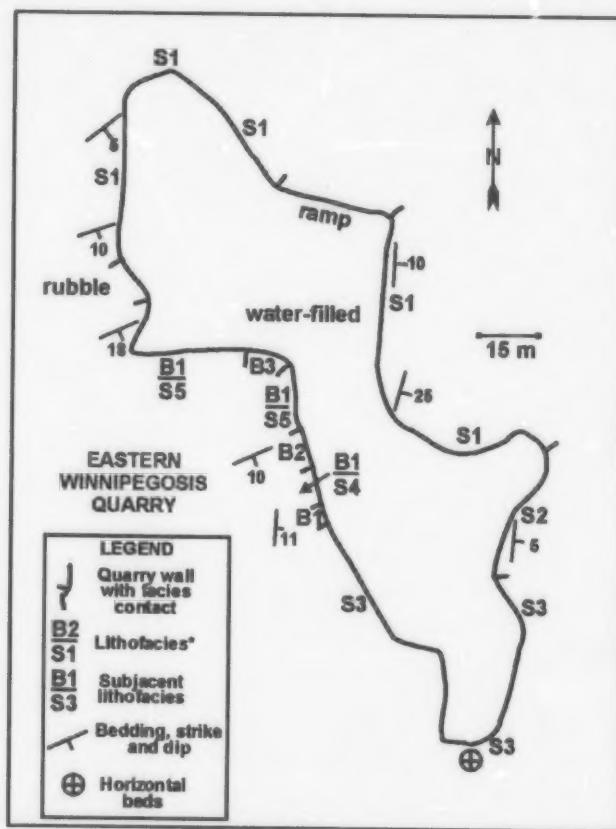


Figure GS-24-2: Location map showing the study area and areas of Souris River Formation outcrop and subcrop (modified from Martiniuk, 1992).



*Lithofacies descriptions in Table GS-24-1

Figure GS-24-3: Geologic map of the eastern Winnipegosis quarry showing the preliminary lithofacies units.

subsequent transmitted-light and cathodoluminescence microscopy. Analyses by X-ray diffraction will be done to determine the mineralogy of the breccia matrix, and the scanning electron microscope will be used to determine the clast textures of the breccia samples. An inductively coupled plasma atomic optical spectroscopy will be used for characterizing minor- and trace-element concentrations in the matrix of the breccia samples.

PROGRESS TO DATE

Geologic mapping of the quarries and descriptions of stratigraphic sections have highlighted the lateral lithological variability of the Sagemace Member exposed in the Winnipegosis quarries. In the east quarry, detailed examination has resulted in preliminary division of the Sagemace Member into eight lithofacies (Fig. GS-24-3; Table GS-24-1). Five lithofacies (units S1 to S5) are relatively unaltered host limestone units, classified using Dunham's (1962) classification scheme. The remaining three units (B1 to B3) are breccia units, characterized based on percent of ultrastables and matrix versus clast supported.

Table GS-24-1: Preliminary lithofacies units in the eastern Winnipegosis quarry.

Unit	Classification	Occurrence
S1	Burrowed, skeletal mudstone to wackestone	Unaltered host rock
S2	Mottled mudstone	Unaltered host rock
S3	Skeletal wackestone to packstone	Unaltered host rock
S4	Skeletal mudstone to packstone	Unaltered host rock
S5	Prominently bedded mudstone	Unaltered host rock
B1	Petromict diamictite to conglomerate	Collapse breccia
B2	Clay-rich petromict diamictite	Collapse breccia
B3	Megaclastic petromict diamictite	Collapse breccia

The host limestone units, which show no obvious deformation, range from burrowed, skeletal mudstone to wackestone (S1) to prominently bedded mudstone (S5). All limestone units have horizontal or gently dipping, medium to thick beds and gradational to interfingering lateral contacts. Skeletal fragments are mainly crinoid ossicles and brachiopod and gastropod shells, with local bulbous stromatoporoids in units S1 and S2. Concentrations of sulfide concretions with iron oxide haloes are found locally in units S1 and S3 and calcite-filled, 2- to 10-cm vugs are common in all units.

The breccia units extend laterally for 67 m and are either petromict diamictites or petromict conglomerates, but vary greatly in clast lithology, clast size and matrix type. Clasts are generally very angular to subangular and range in size from 1 to 200 mm. Based on field observations, some clast lithologies, such as burrowed skeletal mudstone to wackestone and strongly bedded mudstone, are similar to lithologies in the host limestone units elsewhere in the quarry (units S1 and S5). All breccia units are variably weathered, and obvious skeletal fragments are rare to absent.

ACKNOWLEDGMENTS

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SUMMARY

Stratigraphic investigations and drilling programs were carried out for various projects. The Capital Region Project has been completed and the report is in the editing stage. One corehole was drilled at Denbeigh Point (Lake Winnipegosis) to intersect the Precambrian; three coreholes were drilled in the Wekusko Lake-Iskwasum Lake area to test metallic veining in the Red River Formation; and one corehole was drilled at Steeprock River bridge to intersect mineralization within Mesozoic infill. A total of 326.6 m of drilling was conducted this year.

STRATIGRAPHIC INVESTIGATIONS

Capital Region Project

A mineral-resource and land-use assessment of Manitoba's Capital Region (Winnipeg and portions of the surrounding municipalities) was undertaken by the Manitoba Mines Branch and the Manitoba Geological Survey. The study is being conducted in response to the Capital Region Strategy, under development by the Manitoba Round Table. The purpose of this assessment is to provide mineral-resource data for use in municipal development plans for the Capital Region that will legally protect high-quality quarry minerals, such as crushed stone (Bamburak and Bezys, 1995, 1996).

In 1999, eight preliminary maps were released that depict overburden thickness, bedrock topography and mineral resource potential in NTS map sheets 62I/2, /3, /6 and /7. Final versions of these maps, as well as eight maps covering NTS map sheets 62H/10, /11, /14 and /15 are in the final stages of preparation; the accompanying economic report will be released for January 2002 (see Conley, GS-22, this report).

STRATIGRAPHIC COREHOLE DRILLING

Denbeigh Point

Denbeigh Point, located at the northeast end of Lake Winnipegosis, is situated above Archean terrane near the eastern edge of the Superior Boundary Zone (SBZ). Tyrrell (1892) noted marcasite concretions between boulders on Ami, Cormorant and Pemmican islands and large nodules of grey chert within dolomite beds on the shoreline and islands near Denbeigh Point. Cominco Ltd., attempting to locate Mississippi Valley-type deposits, conducted drill programs 8 km south of Easterville in 1971 (Assessment File 91785, Manitoba Industry, Trade and Mines, Winnipeg) and in the late 1990s (Assessment files 72623, 72892, 73009 and 73024, Manitoba Industry, Trade and Mines, Winnipeg). None were found but the Denby Structure, an anorolous Precambrian basement high (McCabe, 1978), and accretionary lapilli within Cretaceous channel fill (Bezys et al., 1996) were identified.

In 1978, corehole M-4-78 was drilled on the west shore of Denbeigh Point, midway along its length, to a depth of 93.5 m and terminated in the Williams Member of the Stonewall Formation. The corehole was deep enough to complement the nearby Cominco Denby No. 1 drillhole and provide a complete stratigraphic section from Precambrian to uppermost Silurian (McCabe, 1978). During the summer of 2001, corehole M-1-01 was drilled near the 1978 corehole site (located within Chemawawin Indian Reservation 3) with the permission of Chief Clarence Easter of Chemawawin Cree Nation (Fig. GS-25-1). The corehole was drilled to provide a continuous stratigraphic corehole for detailed geochemical sampling over this interval, to check for possible fracturing of the lower Ordovician beds, and to determine the nature of the Precambrian (Table GS-25-1). Unfortunately, drilling problems were encountered in the Winnipeg Formation sand and the corehole had to be terminated at 203.3 m.

Wekusko Lake-Iskwasum Lake Area

In 2000, corehole M-4-00 was drilled on a mineralized fracture within Ordovician Red River Formation dolomite in a Manitoba Highways quarry (UTM 14, E445016, N6054470), located south of Wekusko Lake and PTH 39 (Bezys, 2000); however, only thin clots and veinlets were found near the top of the hole. Analytical results of the mineralized surface and core samples are shown in Table GS-25-2.

M. Fedikow of the Manitoba Geological Survey (pers. comm., 1999) reported similar mineralization south of Iskwasum Lake. To determine the extent and nature of the mineralization near this locality, three shallow coreholes (M-2-01, M-3-01 and M-4-01) were drilled (Fig. GS-25-1; Table GS-25-1) along PTH 39, south of Iskwasum Lake. Core from these holes will be sent for analyses.

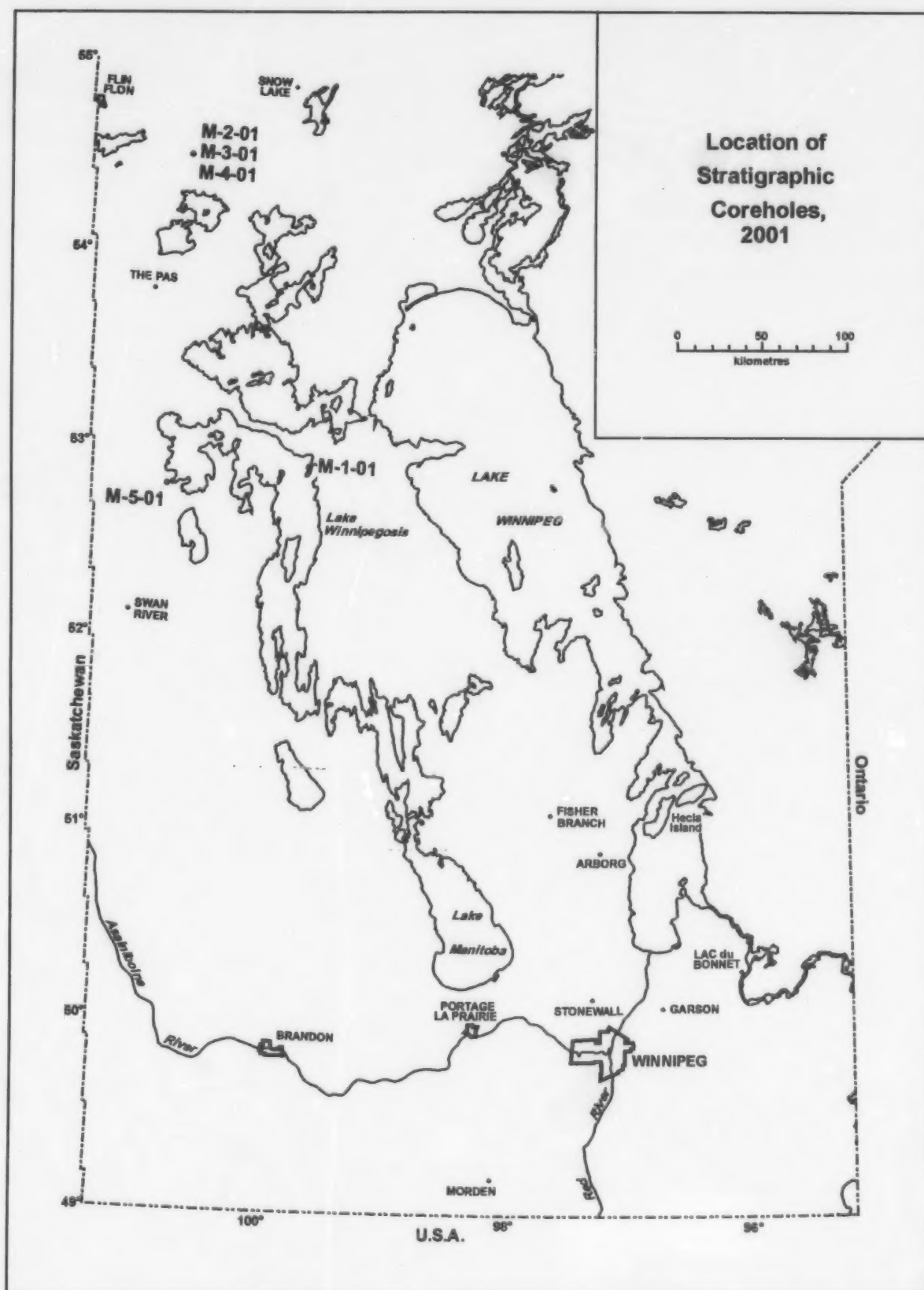


Figure GS-25-1: Location of stratigraphic coreholes, 2001.

Table GS-25-1: Summary of stratigraphic corehole data, 2001.

Hole no.	Location and elevation (m)	SYSTEM/Formation/ (Member)	Interval (m)	Lithology summary
M-1-01 Denbeigh Pt.	12-19-45-16W 5860573N 447396E 254.5	SILURIAN/Interlake Group/ Cedar Lake (V-Marker)	0.0-2.0	Tan wackestone, dolomitic, very broken core
		Cedar Lake	2.0-6.6	Dark grey mudstone
		East Arm	6.6-22.3	Buff packstone, marker beds at 12.0-13.8 and 21.3-22.3 m
			22.3-40.8	Light brown-tan mudstone to wackestone, very hard to distinguish between East Arm and Cedar Lake formations
		(U ₂ -Marker)	40.8-45.6	Green-grey, laminated mudstone
		Atikameg	45.6-50.9	Light brown packstone, lost core
		Moose Lake	50.9-59.9	Light brown-tan wackestone, marker bed at top
		(U ₁ -Marker)	59.9-61.0	Dark brown-grey mudstone, laminated
		Fisher Branch	61.0-75.3	Light brown wackestone, broken and porous core, minor shaly fragments at the base, some corals
		SILURIAN/Stonewall	75.3-82.5	Light brown mudstone to wackestone, laminated, gradational upper contact
				75.3-76.8: Stonewall Marker; grey, laminated mudstone
				78.8-82.5: T-Zone; dark grey, laminated mudstone, burrowed, some rip-up clasts
		ORDOVICIAN/Stonewall (Williams)	82.5-91.0	Light brown wackestone, some bituminous partings
M-2-01 Iskwasum Lake S	11-23-65-23W 6050487N 381619E 311.5	Stony Mountain	91.0-101.5	Brown mudstone, laminated, 0.5 m marker bed at top
			101.5-131.9	101.5-112.3: upper Stony Mountain; very similar to Lower Red River, light brown, mottled wackestone
				112.3-131.9: lower Stony Mountain; very nodular and mottled with bituminous partings
		Red River (Fort Garry) (lower Red River)	131.9-200.3	131.9-149.4: Light grey to brown wackestone, scattered chert, burrowed and fossiliferous
				149.4-200.3: Light brown-tan wackestone, mottled, some chert, burrowed, fossiliferous
		Winnipeg	200.3-203.3	Light to dark grey sandstone, well rounded, medium grained, quartzose, burrowed, abundant flecks of ovoid, flattened fragments (rip-ups) of shaly material, some are pyritic (maybe oolites?), some pyrite and marcasite mineralization present, dolomitic sandstone at top
				Mottled dolomite, buff becoming red below 11.60 m, abundant sand grains near the base
		ORDOVICIAN/Red River (lower)	0.00-18.50	
		Winnipeg	18.50-19.67	Silica sand, ferruginous in upper 4.00 cm, becoming soft at the base, lost 0.50 m of core
		PRECAMBRIAN	19.67-25.19	Mafic gneiss with near-vertical fractures (spacing 0.25-0.50 m) cutting foliation, minor pyrite at base
M-3-01 Iskwasum Quarry W	2-23-65-23W 6050581N 382005E 304.8	ORDOVICIAN/Red River (lower)	0.00-11.30	Mottled dolomite, buff becoming reddish below 5.80 m, abundant sand grains at the base
		Winnipeg	11.30-12.04	Ferruginous silica sand with buff rip-ups of kaolin, silica sand and blue clay
		PRECAMBRIAN (weathered) (unweathered)	12.04-20.05	12.04-14.24: Regolith, abundant pyrite, oxidized, becoming darker downward
				14.24-20.05: Dark green argillite to 17.25 m, soft mud to 17.77 m (lost core), mafic gneiss at the base
M-4-01 Iskwasum Quarry E	7-23-65-23W 6050624N 382151E 304.8	ORDOVICIAN/Red River (lower)	0.0-9.60	Mottled dolomite, buff with minor chert, becoming reddish below 4.37 m, abundant sand grains near the base
		Winnipeg	9.60-10.85	Silica sand, ferruginous in upper 1.06 m, lost 0.50 m of core
		PRECAMBRIAN (weathered) (unweathered)	10.85-17.25	10.85-10.94: Regolith, black shale
				10.94-17.25: Mafic gneiss, some near-vertical fractures
M-5-01 Steeprock River Bridge	5-13-44-25W 5850400N 367300E 260.0 m	OVERBURDEN	0.0-9.0	Brown clay, boulder fragments
		DEVONIAN/Dawson Bay (Middle Beds)	9.0-23.8	Light green-grey limestone, mudstone, crinoidal
		(Lower Beds)		
		(Second Red Beds)	23.8-35.8	Tan limestone, wackestone, stylolitic, fossiliferous
		Transitional Beds	35.8-45.5	Buff to red mudstone, dolomitic
		Winnipegosis (Upper)	45.5-51.6	Limestone breccia, very angular fragments, and tan
			51.6-60.8	Reefal, porous, beige, packstone, fractured

Table GS-25-2: Analytical results of the mineralized surface and core samples of Red River Formation dolomite from Wekusko South Quarry (instrumental neutron activation analysis [INAA], inductively coupled plasma optical emission spectroscopy [ICP-OES] and inductively coupled plasma cold vapour [ICP-CV] geochemistry).

Element	Au	As	Ba	Br	Co	Cr	Cs	Fe	Hf	Ir
Units	ppb	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppb
Method	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA
Detection limit	2	0.5	50	0.5	1	5	1	0.01	1	5
Sample no.										
99-99-SL-002B (surface)	<2	90.4	<50	17.7	44	<5	<1	5.06	<1	<5
99-99-SL-002B (D) (surface)	<2	90.9	<50	17.6	43	<5	<1	4.98	<1	<5
99-99-SL-002A (surface)	<2	73.3	<50	18.8	34	5	<1	3.66	<1	<5
M-4-00-0 (corehole)	<2	19.3	<50	9.9	10	5	<1	1.78	<1	<5
Element	Na	Rb	Sb	Sc	Se	Sn	Ta	Th	U	W
Units	%	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm
Method	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA
Detection limit	0.01	15	0.1	0.1	3	0.01	0.5	0.2	0.5	1
Sample no.										
99-99-SL-002B (surface)	0.03	<15	8.3	0.3	<3	<0.01	<0.5	0.2	3.0	<1
99-99-SL-002B (D) (surface)	0.03	<15	8.5	0.4	<3	<0.01	<0.5	0.3	3.0	<1
99-99-SL-002A (surface)	0.04	<15	6.1	0.4	<3	<0.01	<0.5	0.3	2.9	<1
M-4-00-0 (corehole)	0.02	<15	1.5	0.5	<3	<0.01	<0.5	<0.2	2.0	<1
Element	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu	Mo	Cu
Units	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Method	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	ICP-OES	ICP-OES
Detection limit	0.5	3	5	0.1	0.2	0.5	0.2	0.05	2	1
Sample no.										
99-99-SL-002B (surface)	2.6	4	<5	0.5	<0.2	<0.5	<0.2	<0.05	<2	200
99-99-SL-002B (D) (surface)	2.6	3	<5	0.5	0.2	<0.5	0.2	<0.05	<2	196
99-99-SL-002A (surface)	2.5	5	<5	0.6	<0.2	<0.5	<0.2	<0.05	2	75
M-4-00-0 (corehole)	2.6	5	<5	1.1	0.5	<0.5	0.4	0.06	<2	69
Element	Pb	Zn	Ag	Ni	Mn	Sr	Cd	Bi	V	Ca
Units	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%
Method	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES
Detection limit	5	1	0.5	1	1	1	0.5	5	2	0.01
Sample no.										
99-99-SL-002B (surface)	248	28	1.1	52	1841	46	<0.5	<5	6	17.14
99-99-SL-002B (D) (surface)	226	28	1.1	54	1823	44	<0.5	<5	4	16.70
99-99-SL-002A (surface)	133	21	<0.4	34	1565	44	<0.5	<5	2	16.26
M-4-00-0 (corehole)	24	<1	0.6	13	1037	38	<0.5	<5	2	18.53
Element	P	Mg	Ti	Al	K	Y	Be	S	Hg	
Units	%	%	%	%	%	ppm	ppm	%	ppb	
Method	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-CV	
Detection limit	0.001	0.01	0.01	0.10	0.01	2	2	0.01	5	
Sample no.										
99-99-SL-002B (surface)	0.008	9.30	<0.01	0.11	0.07	4	<2	2.92	362	
99-99-SL-002B (D) (surface)	0.008	9.17	<0.01	0.10	0.07	4	<2	2.73	333	
99-99-SL-002A (surface)	0.004	9.36	0.01	0.11	0.06	3	<2	2.13	233	
M-4-00-0 (corehole)	0.005	14.71	<0.01	0.10	0.07	6	<2	0.43	-	

(D) duplicate sample

Steeprock River

Also in 2001, corehole M-5-01 was drilled at the Steeprock River bridge to intersect possible mineralization within the Mesozoic (Fig. GS-25-1). In 1975, corehole S-4-75 encountered 36.0 m of probable Mesozoic infill with some pyritic mineralization and the Devonian strata were severely disrupted (H.R. McCabe, unpub. rept., 1975). McCabe suggested that the feature might represent a post-Devonian, pre-Cretaceous sedimentary breccia and channel fill. It may also be related to salt collapse or tectonics. Corehole M-5-01 encountered 9.0 m of overburden and had no indication of Mesozoic infill or severely disrupted Devonian strata (Table GS-25-1).

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SUMMARY

In June and July 2001, a gravity and magnetic survey was completed along The Pas Moraine. The survey was completed along Provincial highways 6, 60 and 10. The survey crossed the Superior Boundary Zone almost 90 degrees from strike. The purpose of this survey was to investigate the gravity and magnetic field of the Superior Boundary Zone in this region, and to obtain more information on the possible southern extension of the Thompson Nickel Belt.

INTRODUCTION

Gravity and magnetic surveys were completed during an eight-day survey starting June 26 along The Pas Moraine in central Manitoba in order to obtain a more detailed view of the gravity and magnetic field in the area. Of particular interest in the survey is the response from the Superior Boundary Zone, with possible implications for the extension of the Thompson Nickel Belt beneath the Paleozoic cover. The surveys were carried out along Provincial Highway 6, Provincial Highway 60, and Provincial Highway 10, from south of Grand Rapids to Westray. The survey area is illustrated in Figure GS-26-1.

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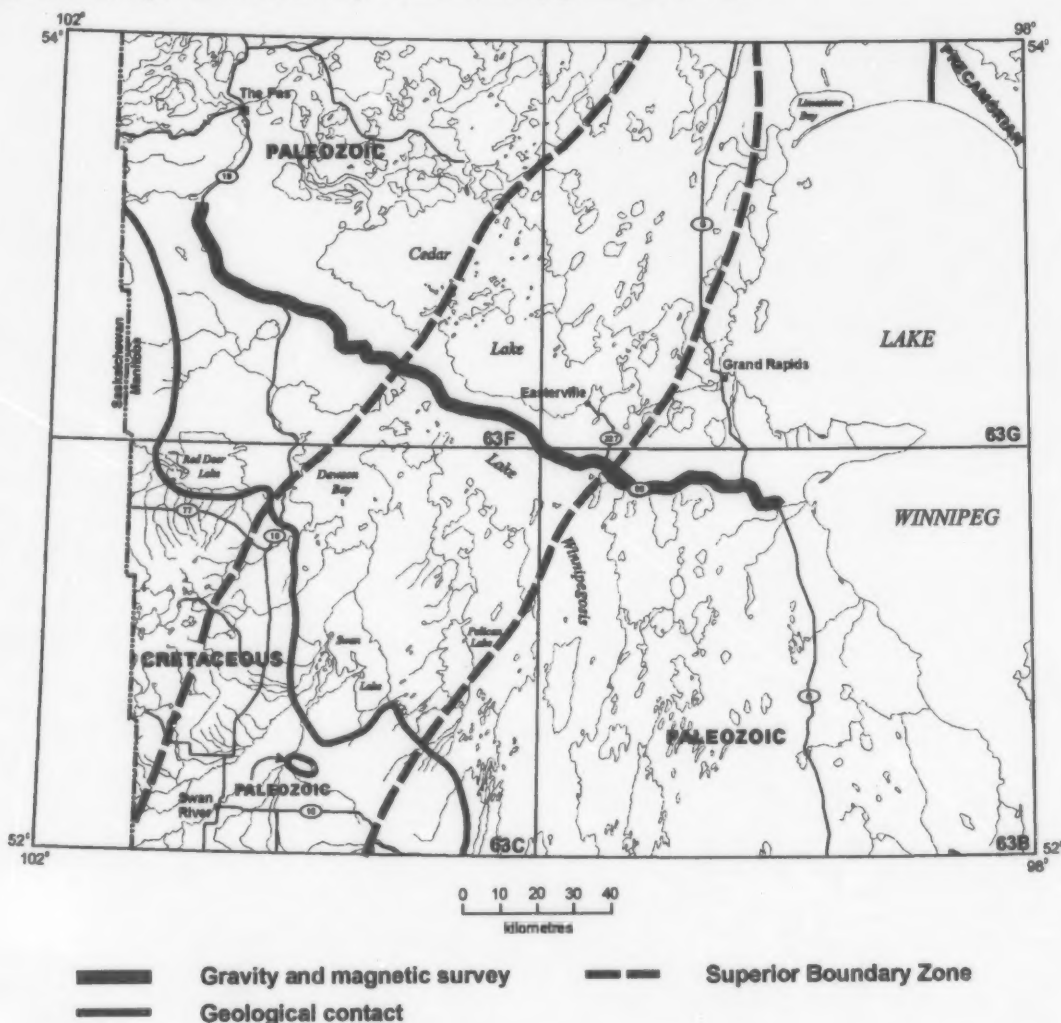


Figure GS-26-1: Location of survey area.

GEOPHYSICAL SURVEYS

Gravity Survey

The gravity survey was completed using a Worden Gravity Meter, no. 543, model III, built by Texas Instruments, with a sensitivity of 0.04 mgal, belonging to the Department of Geological Sciences, University of Manitoba. Readings were taken along the highways at 1 km intervals. The readings were taken in the ditch adjacent to the highway. Two readings were taken at each station location; the results were then averaged. The gravity meter was placed on a tripod approximately 50 cm off the ground when the readings were taken. The gravity survey used a base station in order to correct for drift. The base station was visited approximately every two hours.

The site position was recorded using a Garmin 12 XL global positioning system (GPS). As the elevation data from the GPS is not sufficiently accurate for gravity surveying, station heights relative to the centre of the highway were recorded.

The elevation data was obtained using highway profile maps from the Manitoba Department of Transportation and Government Services. The station location was found on the highway profile and the elevation was read off the profile. The difference between the height of the highway centreline and the station was subtracted from the highway profile elevation, to result in the actual station elevation. Using this procedure, the elevation information is accurate to approximately 50 cm.

Data Reductions

Gravity data needs to be reduced so that only lateral subsurface density variations are represented by the data (Reynolds, 1997). In the processing of the gravity data, the following corrections were made in order to reduce the data to the Bouguer anomaly:

- drift correction (using repeat base-station readings)
- free-air correction

$$\delta g_F = 0.3086h$$

where h is the height differential between stations and δg_F is in mgal

- Bouguer correction

$$\delta g_B = 2\rho G r h$$

where $G = 6.67 \times 10^{-8} \text{ m}^3 \cdot \text{Mg}^{-1} \cdot \text{s}^{-2}$, ρ = density (a density of $2.67 \text{ Mg} \cdot \text{m}^{-3}$ [$2670 \text{ kg} \cdot \text{m}^{-3}$] was assumed) and δg_B is in mgal

- latitude correction

$$\delta g_L = -0.8108 \sin(2\phi)$$

where ϕ is degrees latitude, δg_L is in mgal/km north

The terrain correction was not applied because the survey area had limited relief, and with the assumed density, the correction was negligible. The final reduced data are shown in Table GS-26-1.

Results

The Bouguer gravity anomaly profile is displayed in Figure GS-26-2. There are two definite high areas in the response with a trough in the middle. These spikes are of the order of 60 mgal in amplitude. There are also shorter wavelength (<10 km) and smaller amplitude variations (<3 mgal) toward the eastern end of the survey.

Modelling

Some preliminary two-dimensional modelling of the gravity data was done using the computer program Potent (version 2.0), produced by PC Potentials. A linear regional trend was removed from the data, such that the east and west ends of the survey had a constant value. The bodies in the model were given a strike of 040 degrees, which is consistent with strike of the gravity trends in this region of the province (Geological Survey of Canada, 1995). The aim of the modelling was to combine other geophysical and geological data with the gravity data to derive a model that fit the data. The auxiliary data came from Lucas et al. (1996) and their interpretation of the LITHOPROBE seismic line S3B (Fig. GS-26-3 and -4). The interpreted contacts from the seismic data were used to form lithological bodies, which comprise the bodies in the model. The model consists of 10 two-dimensional polygonal prisms located within the crust. A flat Moho at 40 km depth was used in the modelling. The gravity data were fitted by iteratively adjusting the density of the bodies. The final model is shown in Figure GS-26-5. The data fits fairly well into the model that consists of 10 bodies. The final characteristics of the bodies in the gravity model are shown in Table GS-26-2. The lithological units in the table are from Lucas et al. (1996). The density of the Archean granitoid can be taken as the background density because this rock unit has a density contrast of zero with respect to the actual background density.

This gravity model is only preliminary but shows that the interpreted contacts from LITHOPROBE seismic data agree with the gravity data.

Table GS-26-1: Final reduced data collected along The Pas Moraine.

Station	Northing (m)	Easting (m)	Gravity (mgal)	Total Magnetic Field (nT)
1	5857460	497738	743.9722531	59166.00
2	5857475	496715	744.2860888	59265.90
3	5857392	495685	744.1313447	59245.95
4	5857322	494722	743.4937507	59355.90
5	5857176	493709	741.3558240	59235.27
6	5857234	492656	739.0088650	59215.40
7	5857978	492091	739.6096866	59202.10
8	5859301	491593	741.9407692	59546.90
9	5859953	491338	743.2716683	59484.60
10	5860830	490967	743.3221563	59537.70
11	5861496	490206	742.0189398	59470.80
12	5862035	489344	743.1606265	59492.50
13	5862513	488508	743.4934354	59448.80
14	5862679	487749	742.9932876	59706.90
15	5861874	487068	742.3997261	59598.18
16	5861496	486161	741.5788324	59477.80
17	5861382	485161	740.7498255	59483.92
18	5861382	484152	740.4921680	59493.01
19	5861664	483190	740.2230045	59481.64
20	5862023	482292	740.0620327	59439.55
21	5862535	481389	739.3329319	59241.70
22	5863077	480487	738.8426297	59217.16
23	5863100	479528	739.1086199	59623.78
24	5863626	478620	738.5347946	59351.72
25	5864045	477706	738.6015566	59279.00
26	5864076	476756	736.5155847	59282.96
27	5864108	475750	734.9990135	59323.42
28	5864281	474724	734.1808311	59258.20
29	5864173	473717	734.8860859	59326.98
30	5863699	472857	735.3186972	59412.60
31	5863198	471947	734.7419093	59509.96
32	5862697	471050	731.1967151	59457.29
33	5862220	470186	728.3287944	59457.83
34	5861737	469297	725.0024528	59435.69
35	5861284	468387	725.6697235	59449.56
36	5861146	467384	724.5757523	59483.31
37	5861256	466386	726.2760048	59400.05
38	5861693	465490	727.1629032	59392.42
39	5861720	464496	727.6946178	59481.54
40	5861645	463460	729.4216002	59472.91
41	5861577	462474	729.1575168	59597.28
42	5861340	461472	727.9231734	59543.02
43	5860937	460556	728.2533234	59614.89
44	5860717	459544	728.8495620	59586.26
45	5860960	458655	731.4334554	59459.80
46	5861766	457955	733.2350541	59619.62
47	5862443	457211	733.6151633	59647.50
48	5862889	456276	734.2222623	59636.30
49	5862836	455271	732.9252051	59714.90
50	5863132	454312	730.5885528	59675.80
51	5863914	453649	732.6766898	59603.40
52	5864672	453012	733.4944905	59568.90
53	5865555	452606	735.3543983	59624.60
54	5866326	451949	734.6725809	59630.90
55	5867064	451211	733.8296251	59686.62
56	5867726	450479	732.9635208	59513.34
57	5868214	449621	733.8480091	59540.04
58	5868479	448633	736.6394109	59492.73
59	5868748	447626	735.8752308	59464.42
60	5869015	446633	737.4053964	59398.61
61	5868690	445706	738.4103762	59330.06
62	5868325	444769	737.1820129	59314.50
63	5867975	443809	737.3085898	59306.72
64	5867849	442850	737.7005983	59254.88
65	5868174	441892	739.116316	59187.55
66	5868765	441041	748.5230237	59268.71
67	5869227	440120	758.2093043	59211.56
68	5869229	439147	763.0929512	59143.72
69	5869331	438139	767.7330879	59169.97

Station	Northing (m)	Easting (m)	Gravity (mgal)	Total Magnetic Field (nT)
70	5869710	437212	767.9701777	59167.82
71	5870284	436414	769.3696920	59265.48
72	5870910	435552	772.1402273	59102.34
73	5871500	434749	774.7351580	59081.19
74	5872074	433958	776.3022025	59235.85
75	5872278	432960	778.6744332	59088.51
76	5872989	432342	780.4651730	59059.87
77	5873826	431897	782.0178223	59016.64
78	5874737	431391	784.0072984	59040.72
79	5875634	430917	785.3528216	59050.30
80	5876544	430415	783.6337647	59069.72
81	5877180	429692	779.7810773	59061.34
82	5877699	428786	774.2220911	59075.27
83	5878178	428786	769.1983987	59078.19
84	5878683	427051	765.6588199	59079.77
85	5879178	426178	768.7475098	59125.70
86	5879676	425304	760.3961358	59136.66
87	5880187	424411	753.9110155	59187.24
88	5880578	423496	749.8280363	59226.32
89	5880961	422546	746.9027434	59215.90
90	5881333	421606	746.2914727	59232.32
91	5881442	420593	745.4162685	59239.54
92	5881511	419599	742.3583427	59215.49
93	5881602	418577	738.1790844	59223.27
94	5881698	417589	732.3618337	59219.16
95	5881798	416555	737.7796155	59215.06
96	5882048	415571	737.4134989	59288.89
97	5882311	414596	737.7122512	59253.78
98	5882554	413626	734.8879958	59253.18
99	5882524	412622	735.9857197	59274.57
100	5883075	411651	735.6250263	59229.40
101	5883330	410675	736.9673896	59215.85
102	5883584	409678	738.7493801	59199.24
103	5883837	408706	736.4793746	59211.58
104	5884103	407716	736.5330316	59191.93
105	5884341	406719	735.2246819	59237.33
106	5885025	405980	747.7614939	59209.64
107	5885941	405531	747.1432290	59198.44
108	5886849	405094	750.4192911	59186.75
109	5887767	404650	752.5342564	59195.10
110	5888691	404204	754.4560572	59160.37
111	5889599	403755	756.4977221	59171.76
112	5890400	403182	760.1159684	59163.62
113	5891006	402378	760.6776792	59166.42
114	5891600	401576	761.5865390	59149.82
115	5892235	400721	769.2519369	59172.13
116	5892737	399873	767.7540419	59191.89
117	5892935	398931	768.7791588	59361.61
118	5893142	397931	767.5023364	59455.42
119	5893361	396900	767.3922911	59405.51
120	5893562	395935	767.5606731	59364.65
121	5893764	394957	770.2467272	59306.56
122	5894020	393952	771.7283506	59195.60
123	5894667	393192	768.2315568	59179.71
124	5895431	392545	767.6893795	59217.75
125	5896209	391882	766.7341583	59203.16
126	5896771	391019	766.7548480	59128.77
127	5896880	389985	767.5101022	n.a.
128	5896968	389021	767.2398117	59103.65
129	5897036	387986	765.1131855	59097.56
130	5897059	386964	756.8956568	59217.50
131	5897396	386026	759.7580775	59131.95
132	5898220	385491	759.2532084	59123.74
133	5899256	385260	760.0071610	59100.86
134	5899980	384754	759.3083813	59128.30
135	5899927	383757	757.3757418	59094.76
136	5899803	382765	757.8697757	59104.63
137	5899648	381769	758.1946631	59137.06
138	5899659	380732	757.4708172	59159.01

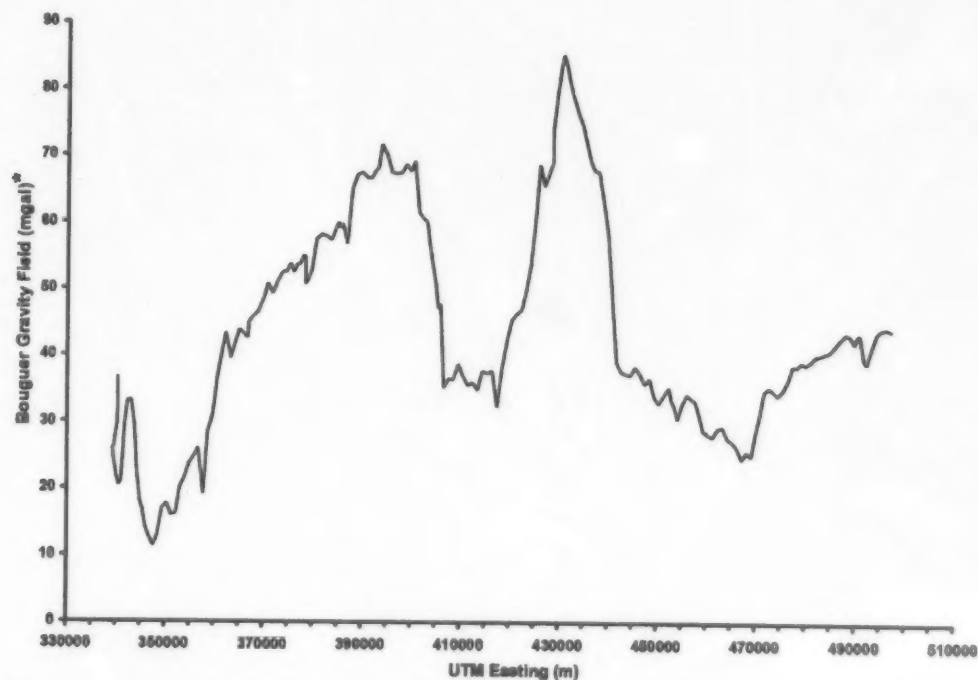
Note: n.a. – not available

Table GS-26-1: Final reduced data collected along The Pas Moraine. (continued)

Station	Northing (m)	Easting (m)	Gravity (mgal)	Total Magnetic Field (nT)
139	5900052	379772	752.8388751	59162.47
140	5900567	378921	751.3308050	59181.93
141	5901453	378444	750.7670867	59174.88
142	5902431	378475	751.1539582	59195.34
143	5903456	378473	752.4656099	59197.28
144	5904488	378501	754.9285824	59197.15
145	5905386	378051	754.9059180	59227.49
146	5906147	377381	753.7807690	59222.32
147	5906910	376730	753.6321773	59237.49
148	5907675	376082	752.5488548	59320.82
149	5908429	375444	753.7855193	59162.32
150	5909245	374763	752.6658824	59212.82
151	5909598	373824	752.4613443	59178.32
152	5909823	372843	751.1948798	59242.32
153	5910042	371852	749.3544261	59243.82
154	5910260	370863	750.7393139	59338.32
155	5910479	369881	748.3624167	59357.82
156	5910694	368881	746.5509168	59343.82
157	5910903	367927	745.8498502	59378.82
158	5911333	366974	744.9044811	59425.99
159	5911837	366837	742.6546755	59418.91
160	5912330	365127	743.8360134	59406.70
161	5912808	364239	741.7998561	59423.50
162	5913259	363401	739.5699152	n.a.
163	5913055	362392	743.3699025	59419.82
164	5913546	361632	740.7737708	59461.20
165	5913890	360738	737.0049555	59450.00
166	5914164	359740	731.2939461	59431.72
167	5914196	358727	728.4532679	59437.51
168	5914374	357733	719.2326881	59480.44
169	5914642	356731	726.0349467	59434.99
170	5914896	355784	724.6576232	59416.28
171	5915336	354876	723.6880104	59422.71

Station	Northing (m)	Easting (m)	Gravity (mgal)	Total Magnetic Field (nT)
172	5915776	353980	721.5415817	59423.76
173	5916014	353010	720.1496355	59428.69
174	5916663	352237	716.2876046	59355.74
175	5917086	351241	715.9991811	59344.92
176	5917427	350323	717.7264784	59344.85
177	5917777	349389	717.0336991	59326.86
178	5918172	348418	712.7592863	59264.36
179	5918666	347565	711.4071499	59289.79
180	5918970	346620	712.8753619	59230.80
181	5919717	345921	714.4153984	59249.31
182	5920575	345438	716.5724935	59246.40
183	5921470	344902	718.0726629	59289.41
184	5922430	344719	718.2000676	59356.41
185	5923468	344785	718.6938585	59384.42
186	5924406	344523	720.3940734	59276.85
187	5925405	344185	723.2860610	59200.27
188	5926346	343996	726.4345840	59157.20
189	5927343	343690	729.9990379	59339.71
190	5928149	343081	733.2728764	59403.22
191	5928828	342275	732.9728171	59767.12
192	5929689	341782	729.9683254	59818.09
193	5930637	341373	724.8825867	59445.11
194	5931550	340965	720.8761342	59252.95
195	5932510	340522	720.4696566	59449.86
196	5933335	340016	721.9054533	59718.21
197	5934223	339475	724.4513863	59656.05
198	5935139	339249	725.9881211	59865.40
199	5936141	339587	726.1680679	59645.75
200	5937090	339904	728.3252691	59641.54
201	5938036	340222	729.5421650	59344.33
202	5939018	340349	733.2706124	59253.62
203	5940062	340250	736.7634993	59236.96

Note: n.a. - not available



*700 mgal is subtracted from the reduced gravity readings.

Figure GS-26-2: Profile of the Bouguer gravity anomaly showing two gravity peaks of approximately 60 mgal.

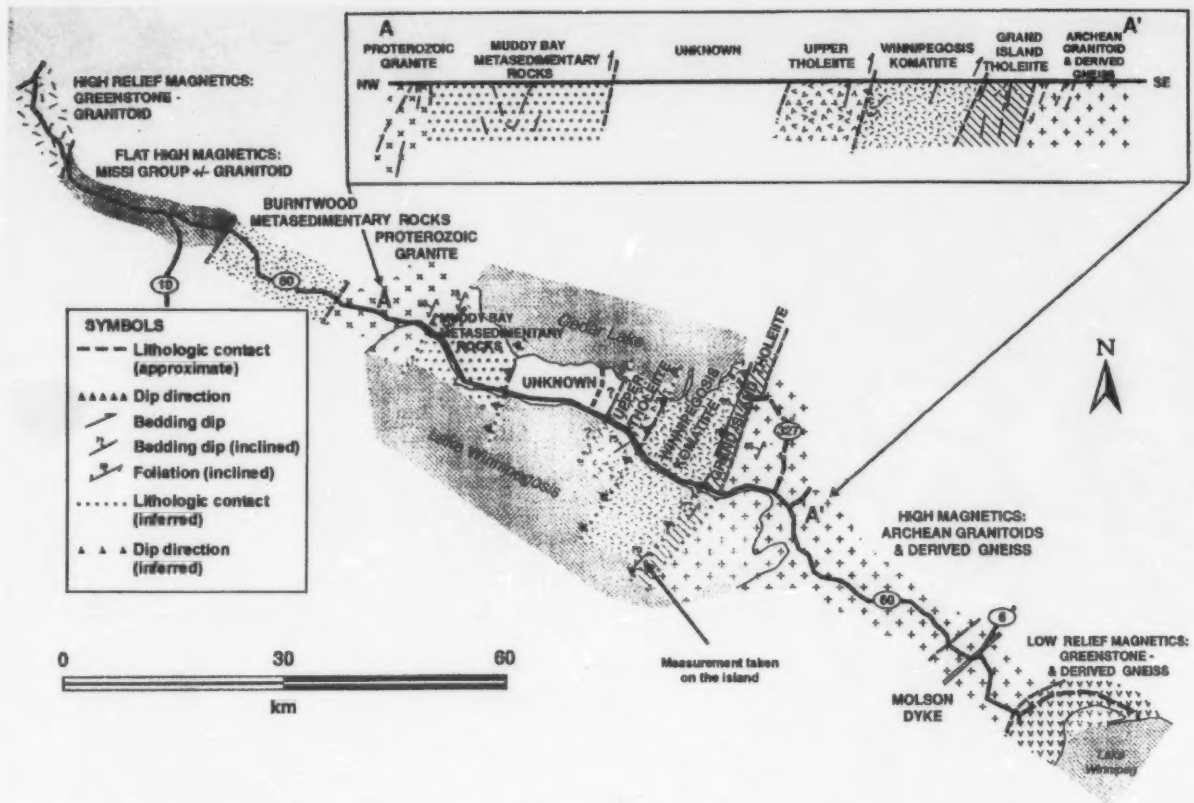


Figure GS-26-3: Map view of lithological units in survey area (from Lucas et al., 1996).

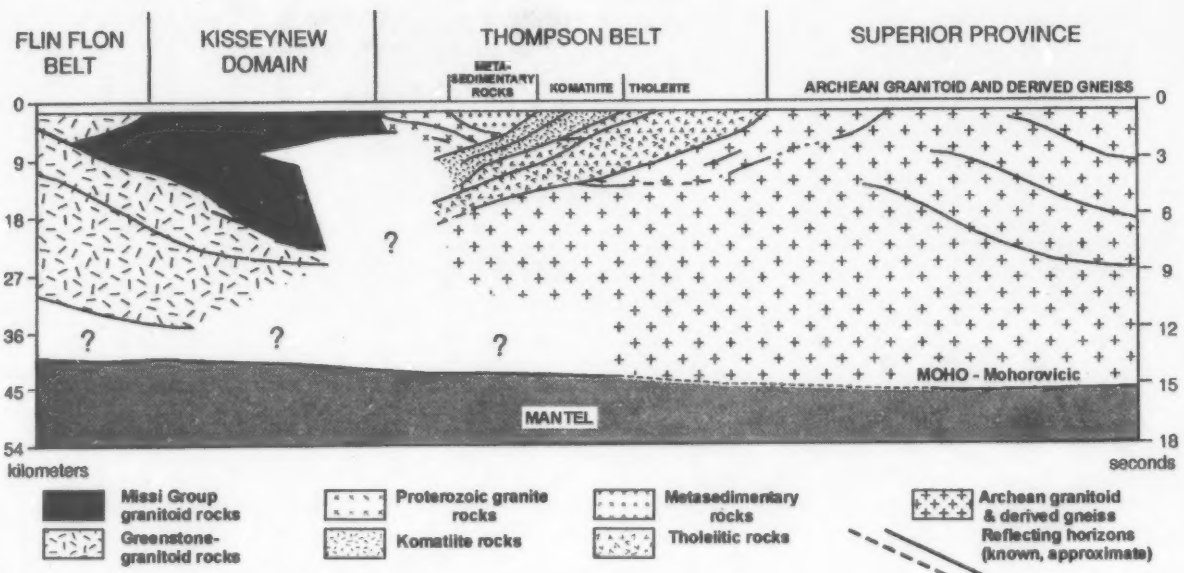


Figure GS-26-4: Seismic model along Line S3B (from Lucas et al., 1996).

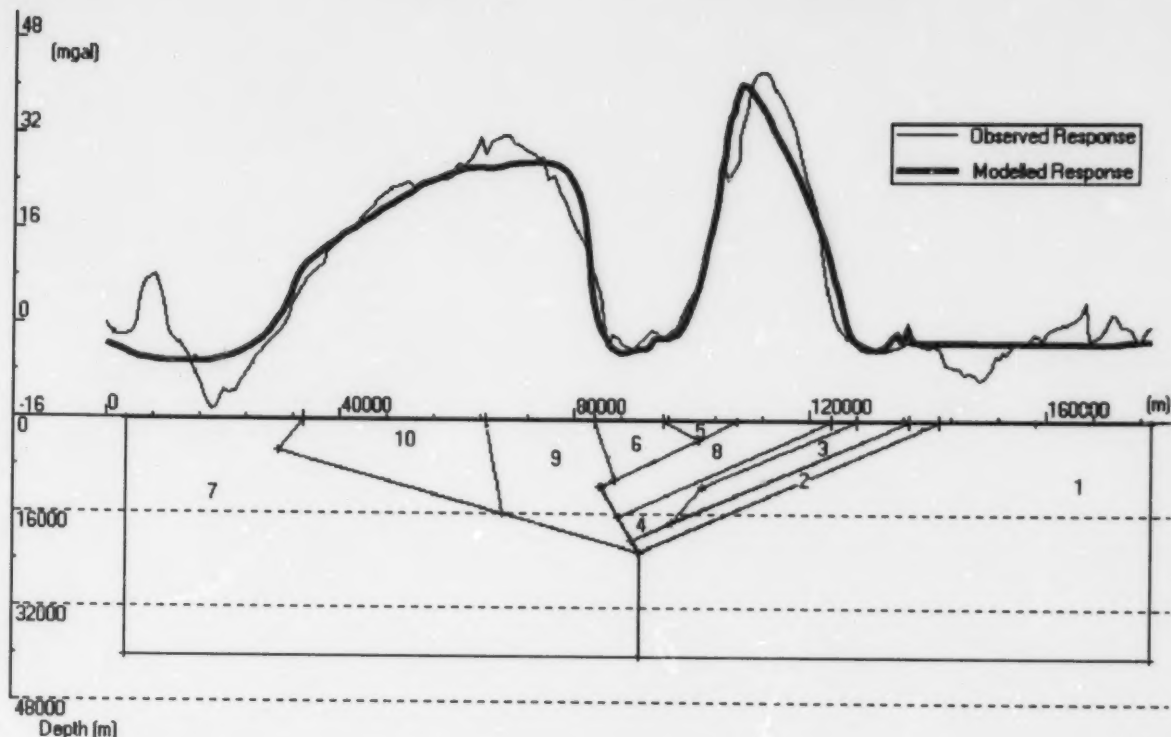


Figure GS-26-5: Preliminary model fitted to the gravity data. The model consists of 10 crustal bodies.

Table GS-26-2: Typical and average analyses of selected elements and element ratios.

No.	Rock name	Body type	Depth (m)	Strike (deg)	Dip (deg)	Plunge (deg)	Density (g/cm ³)
1	Archean granitoid	polygonal prism	250	40	90	0	0.00
2	Grand Island tholeiite	polygonal prism	250	40	90	0	-0.01
3	Winneposis komatiite	polygonal prism	250	40	90	0	-0.05
4	Upper tholeiite	polygonal prism	250	40	90	0	0.23
5	Muddy Bay metasedimentary rocks	polygonal prism	250	40	90	0	-0.35
6	Proterozoic granite	polygonal prism	250	40	90	0	-0.19
7	Greenstone/granitoid	polygonal prism	250	40	90	0	-0.01
8	Unknown	polygonal prism	250	40	90	0	0.16
9	Burntwood metasedimentary rocks	polygonal prism	250	40	90	0	0.05
10	Missi Group	polygonal prism	250	40	90	0	0.06

Magnetic Survey

The magnetic survey was completed using the Scintrex MP-3 Proton Magnetometer, with a sensitivity of 1 nT. Total magnetic field readings were taken at the same stations as the gravity measurements. Two total magnetic field readings were taken at each station and then averaged. A magnetic base station was used and was revisited approximately every two hours.

Data reductions

The magnetic field drift was removed from the data by using a base station with total magnetic field repeat readings. The final reduced data are shown in Table GS-26-1.

Results

The total magnetic field profile is shown in Figure GS-26-6. There are numerous high-frequency, high-amplitude spikes in the response but there are also general magnetic trends that can be seen (including the rise from 350000 to 370000 east). Initial comparison of the Bouguer gravity anomaly and total magnetic field suggests an inverse correlation.

Modelling

Some preliminary two-dimensional modelling of the magnetic data was done using the same computer program as the gravity data (Potent). A linear regional trend was removed from the data, such that the east and west ends of the survey had

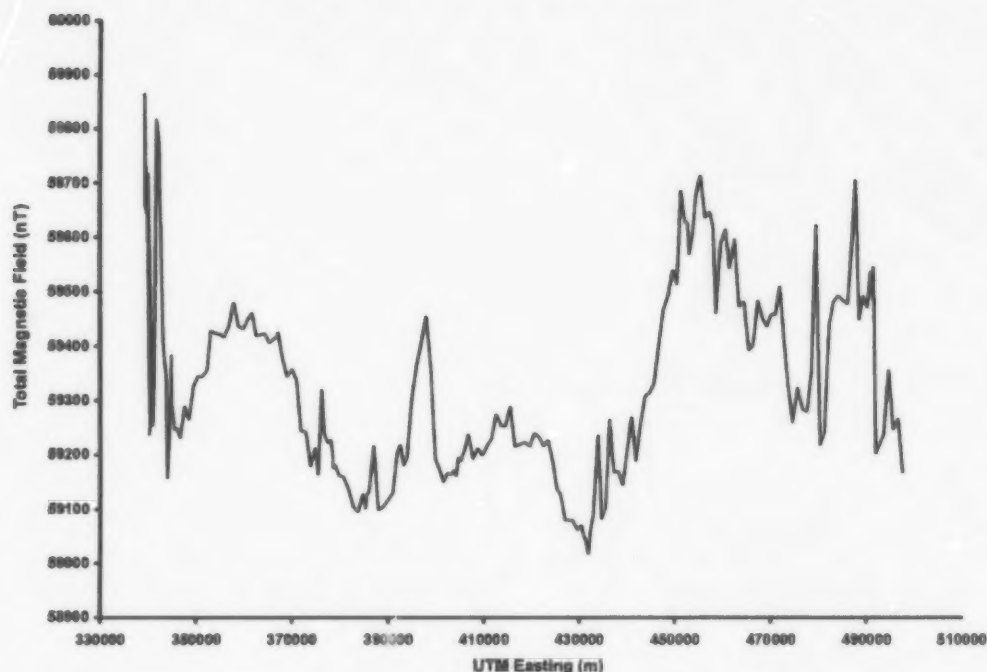
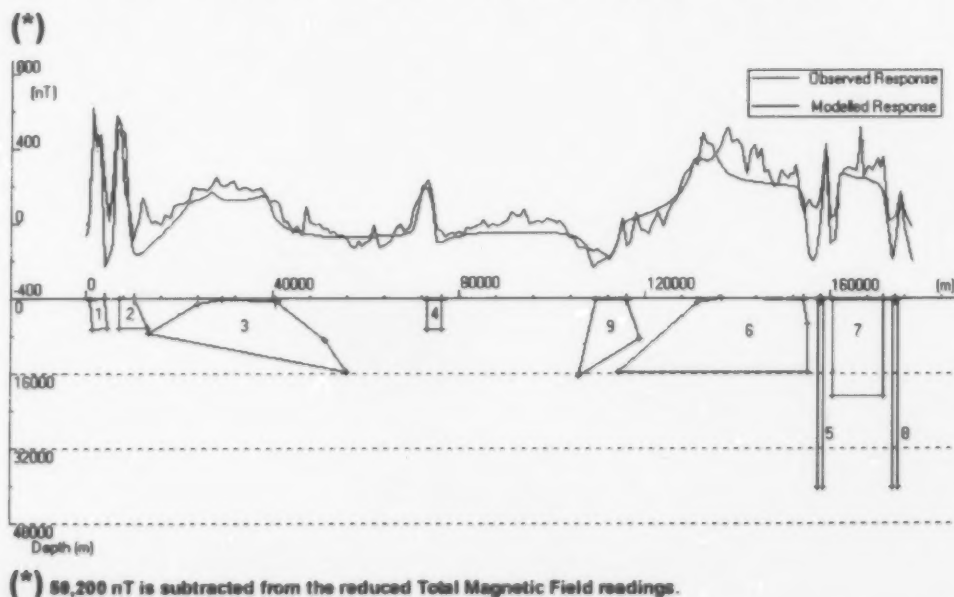


Figure GS-26-6: Profile of total magnetic field response. An inverse relation with the Bouguer gravity anomaly is evident

the same value. The aim of the modelling was to provide a very simple model that fit some of the general magnetic trends in the data. Since the magnetic response is less sensitive to depth, the model was confined to the upper crust. These data were modelled based on susceptibility; however, it is possible that some of the response is due to remanence. The model consists of seven polygonal prisms, located in the upper crust, and two dykes. The data were fitted by iteratively adjusting the magnetic susceptibility, and the apexes of the bodies. In this model, the inducing field was given a magnitude of 59 000 nT, an Azimuth of 014 degrees and an inclination of -69 degrees. As with the gravity data, the bodies were given a strike direction of 040 degrees. The final model is illustrated in Figure GS-26-7. The bodies in this model are poorly resolved at depth. Some drastic changes in the depth of the apexes of the bodies do not greatly affect the magnetic response. The model shows agreement with the gravity model in that the larger bodies (9, 6 and 3) show the same dip directions as the gravity bodies in this area. The characteristics of the bodies of the magnetic model are given in Table GS-26-3.



(*) 59,200 nT is subtracted from the reduced Total Magnetic Field readings.

Figure GS-26-7: Preliminary model fitted to the magnetic data. This model consists of nine upper crustal bodies, including two dykes.

Table GS-26-3: Characteristics of the bodies in the magnetic model.

No.	Body type	Depth (m)	Strike (deg)	Dip (deg)	Plunge (deg)	Susceptibility (SI)
1	polygonal prism	80	40	85	0	0.0280
2	polygonal prism	80	40	89	0	0.0273
3	polygonal prism	571	40	90	0	0.0126
4	polygonal prism	250	40	90	0	0.0122
5	dyke	250	40	90	0	0.0332
6	polygonal prism	286	40	90	0	0.0196
7	polygonal prism	250	40	90	0	0.0183
8	dyke	250	40	90	0	0.0198
9	polygonal prism	250	40	90	0	-0.0070

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- Lucas, S.B., White, D.J., Bleeker, W., Hajnal, Z., Lewry, J. and Weber, W. 1996: Crustal structure of the Superior Boundary Zone (Thompson Belt) from new LITHOPROBE seismic reflection data; *in* Proceedings of LITHOPROBE Trans Hudson Orogen Transect Workshop, Saskatoon, Saskatchewan, May 1996, LITHOPROBE Report 55, p. 82-94.
- Reynolds, J. M. 1997: Introduction to applied and environmental geophysics; John Wiley & Sons Ltd., West Sussex, England, 796 p.



Groom, H.D. 2001: Aggregate inventories: Churchill area, Rural Municipality of Grandview and selected Areas of Special Interest; in Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 172-178.

SUMMARY

Aggregate inventories were carried out in the Churchill area, the Rural Municipality (R.M.) of Grandview and several crown-land parcels (Areas of Special Interest) in southern Manitoba. Office compilation was followed by site inspection and backhoe testing, where required. Samples were field sieved and a representative portion of the fine fraction was sent to Winnipeg for processing. Approximately 300 sites were visited and 100 samples taken. This year, some of the new pits, quarries and access roads were mapped digitally, using a Trimble Geo3 global positioning system (GPS) unit.

CHURCHILL

Since the first European contact in the early 1600s, the Churchill area has been a centre of modern northern activity. First visited by explorers looking for the Northwest Passage, it became an important centre for the fur trade and was a strategic military post in the wars between France and England for control of North America. Later it became a transportation hub with the building of the railroad in 1929, the grain elevator and Port of Churchill in 1931 and the airport during World War II (see also Johnson [1987]). Following the war, both Canada and the United States maintained a large military presence, using it as a base for arctic research. The rocket research range was built in the late 1950s and operated until the mid-1980s. Part of these facilities now house the Northern Studies Centre, which is used by scientists doing biophysical, geologic and climate change studies.

The withdrawal of the military left Churchill with a large established infrastructure and a small population to support it. Tourism has become the major industry. Tourists from around the world come to see polar bears and northern lights, beluga whales and birds in a pristine natural environment. One legacy of the construction booms of previous decades is a large number of abandoned gravel pits along all roads in the area. Vegetation growth is very slow in this region and pits that are decades old still have not revegetated. This has led to a conflict between the need to maintain an undisturbed habitat for eco-tourism and species preservation and aggregate extraction, also necessary for tourism and other industries that support the town.

The Town of Churchill and the Manitoba departments of Conservation and Industry, Trade and Mines requested the aggregate inventory that was carried out this summer. The results will become one layer in a land-use planning map that could guide future extraction sites.

Location and Scope

The scope of the study was to inspect all existing aggregate sites and test unopened deposits within a reasonable distance of accessible haulage roads. This defined an area bounded on the west by Churchill River, on the north by Hudson Bay, extending eastward approximately 26 km and 20 km south of Hudson Bay. It falls within theoretical townships 110 to 113, ranges 20E prin. mer. to 2E of 2nd mer. (Fig. GS-27-1) on NTS map sheets 54K and 54L.

Previous Works

Many geological investigations have been carried out in the Churchill region since R. Bell of the Geological Survey of Canada visited the area in 1879. There are comprehensive accounts of earlier works in Dredge and Nixon (1992) and Bamburak (2000).

The surficial geology and glacial history of northeastern Manitoba, including the Churchill area, is detailed in Dredge and Nixon (1992). Maps of the surficial geology of Churchill are presented at 1:500 000 in Dredge and Nixon (1992) and at 1:250 000 in Dredge and Nixon (1980a, b). A biophysical map, at a scale of 1:50 000, was prepared by Terrain Analysis Services for Manitoba Hydro (Manitoba Hydro, unpub. rept., 1994). This map outlines potential aggregate deposits and other surficial units.

Young (1982a, b) mapped the sand and gravel deposits of the area, as well as testing Precambrian outcrops for their aggregate capabilities. The report by Bamburak (2000) on the industrial mineral potential of the area excluded sand and gravel but noted the use of bedrock quarries as aggregate sources.

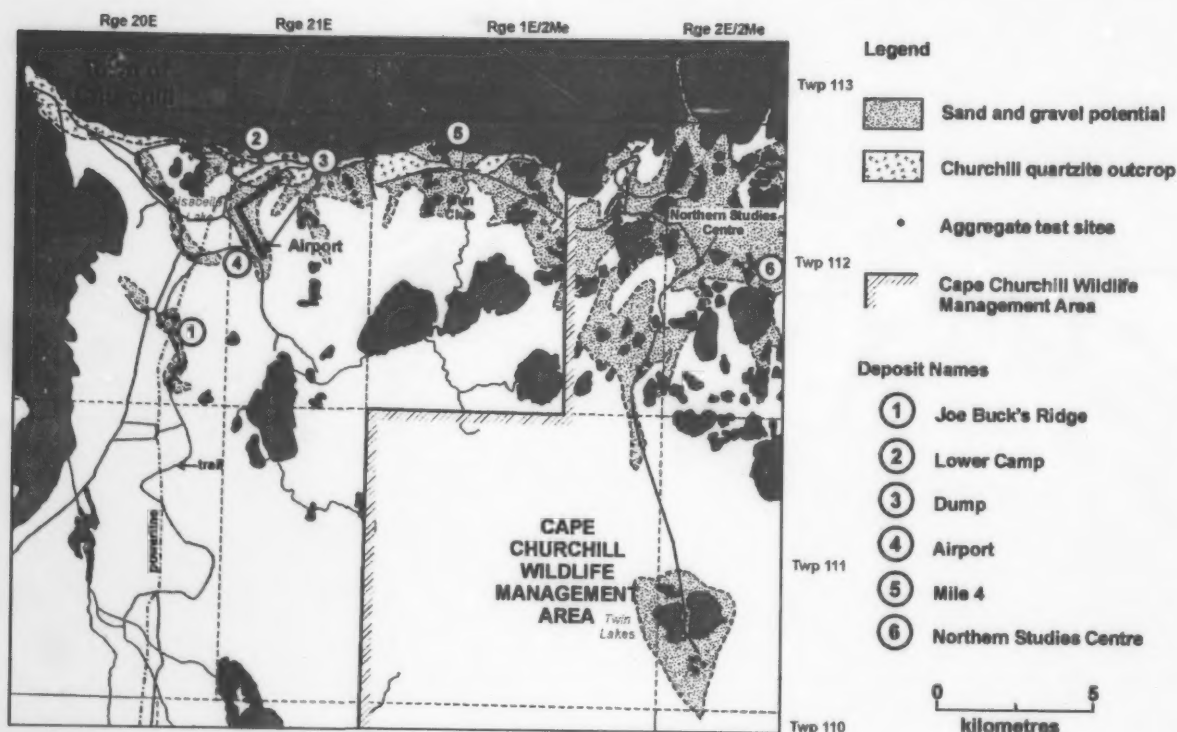


Figure GS-27-1: Location map of the Churchill area; showing potential aggregate deposits and quartzite outcrop.

Geology

Bedrock

The Precambrian Churchill quartzite outcrops as a discontinuous ridge in the study area. The ridge runs eastward along the coast for approximately 20 km then continues southwest of the study area on the west side of Churchill River. It is approximately 10 m high, up to 0.5 km wide in places and has been strongly moulded by glacial action. The rock is predominantly a grey, massive, medium- to fine-grained quartzite; in places crossbedded structures are preserved. Where the rock is fractured, it has weathered to a rusty orange.

Paleozoic rocks of Silurian and Ordovician age flank the quartzite ridge on both the north and south sides. Where seen in outcrop, the rocks are generally buff-coloured dolomite or limestone; commonly they are highly fossiliferous. In 1998, the world's largest trilobite fossil was found near Churchill (Bamburak, 2000).

Refer to Bamburak (2000) and Dredge and Nixon (1992) for more detailed bedrock descriptions.

Quaternary

Dredge and Nixon (1992) provides a detailed description of Quaternary events and surficial materials in the Churchill area. The following history is summarized from that work.

During the Wisconsin glacialiation, ice flow from the north (Keewatin) and the east (Hudson/Labradorean) affected northeastern Manitoba. Tills deposited by eastern ice are silty and carbonate rich. Tills deposited by the northern ice, are normally sandy and contain predominantly Precambrian clasts. By the time the glaciers reached Churchill, the tills had become carbonate enriched through the incorporation of Paleozoic bedrock and earlier carbonate-rich tills. The margin between these ice sheets fluctuated considerably over time but the main Late Wisconsin ice flow in the Churchill area was from the north (Dredge and Nixon, 1992). Eskers with a north orientation, such as the Christmas Lake esker east of Churchill, support the presence of south flowing ice at the end of the last glacialiation.

During deglaciation, freshwater glacial Lake Agassiz formed at the ice front, originally along the suture between the two ice masses. It is not clear that glacial Lake Agassiz ever extended over the Churchill area. As the Hudson ice retreated into Hudson Bay, ocean waters flowed in front. The ice front may have been west and south of Churchill at this time (Dredge and Nixon, 1992).

Because the land surface had been depressed by the weight of the ice, marine waters of the Tyrell Sea rose to elevations of greater than 165 m above sea level (a.s.l.) approximately 7700 years BP. Due to isostatic rebound, the Tyrell Sea gradually regressed towards present day Hudson Bay and the marine beaches that form the major aggregate deposits in current use were formed less than 2000 years BP (Dredge and Nixon, 1992).

Aggregate Inventory

The aggregate inventory consisted of office compilation and three weeks of fieldwork. Office compilation was carried out by:

- Compiling active pit and quarry locations, as well as quarry lease and withdrawal locations, from the Mines Branch quarry database
- Compiling pit and sample locations from the Department of Transportation and Government Services Block files
- Compiling depleted pit and identified rehabilitation sites from Inspection and Rehabilitation Services, Mines Branch
- Transferring data to a 1:50 000 digital biophysical base map provided by Manitoba Hydro; this map had potential sand and gravel deposits and bedrock outcrops delineated
- Airphotos from 1993 (1:20 000 scale) and 1974 (1:35 000 scale) were used in conjunction with the above map to design the field program

Fieldwork was carried out in conjunction with Irv Hiller of the Materials and Research Branch of Manitoba Department of Transportation and Government Services. Fieldwork began with site inspection of all known pits and quarries. Pits were examined for type of material, degree of depletion and active/inactive/depleted status. A Trimble Geo3 GPS unit, which has mapping capabilities and an accuracy of 1 to 5 m, was used to record the perimeters of active pits and quarries. Unopened portions of deposits were inspected and land uses or physical properties that would limit extraction noted.

Due to the environmental and tourism issues that prompted this inventory, several people led field trips to highlight areas of concern to various stakeholders. Cam Elliot and Glenn Sugget, Department of Conservation, showed us areas used by the tour operators, particularly within the Cape Churchill Wildlife Management Area. Darren Ottaway, CEO of the Town of Churchill, showed us sites related to both the need for aggregate for public works and for recreational use by local residents, such as Lion's Park playground at Isabelle Lake. Peter Scott of the Northern Studies Centre took us to plots laid out by scientists for their ongoing studies. These factors were kept in mind when determining the backhoe program.

Merv Walkoski, of Merv's Excavating Co., was hired for the backhoe program. He is a long-term resident, the only local aggregate operator in the area and has been the backhoe operator for most of the previous testing programs. As such he has extensive knowledge of the aggregate and had already tested some of the deposits selected for this backhoe program. Given the local sensitivity against disturbing vegetation due to its long regrowth period, we did not retest deposits that M. Walkoski had recently excavated. For these we used a GPS unit to determine the location of each old hole and recorded the approximate depth and material type as he recalled it. Twenty-five such holes were recorded.

Fifty new testholes were dug. The backhoe had a reach of greater than 8 m but most holes were 1 to 3 m deep as permafrost was often the limiting factor. Testholes were deeper in the base of old pits where the removal of the insulating peat layer resulted in the lowering of the permafrost level. (Fig. GS-27-2). Backhoe site locations were noted using a Garmin 12 XL GPS unit as well as the Trimble in order to test the relative accuracy of the much more affordable Garmin.

Sixty-six gravel samples were shipped to Winnipeg for sieve analysis by the Department of Transportation and Government Services. In addition, five samples were taken to be analyzed for salt content.

Aggregate Deposits

There are four bedrock quarries in the study area; one in the Churchill quartzite and three in limestone outcrops. The three active quarries, the quartzite and two of the limestone quarries, are operated by M. Walkoski in an area locally referred to as



Figure GS-27-2: Backhoe testing at the base of old pit; Twin Lakes deposit.

the "lower camp" site (sec.30 and 31, twp. 112, rge. 21, E prin. mer.). They are a major aggregate source. The third limestone quarry is near the Northern Studies Centre and has not been used since the project to reactivate the Rocket Launch site was abandoned.

There are six active sand and gravel areas, informally referred to as: 1) Joe Buck's Ridge, 2) Lower Camp, 3) Dump, 4) Airport Pit, 5) Mile 4 and 6) Northern Studies Centre (Fig. GS-27-1).

While the Joe Buck's Ridge and Dump deposits both have remaining gravel reserves, it is the sand in each deposit that is important. The sand at the south end of Joe Buck's Ridge has a low salt content making it one of the few deposits in the area that can meet specifications for concrete. The Dump pit is the only known source of VMA sand — an important element for asphalt production (D. Kernot, Mulder Construction, pers. comm., 2001). This resource is currently being sterilized by the dumping of chaff from railway boxcars.

The aggregate portion of the Lower Camp deposit is nearing depletion. The best gravel remaining is under the trail, which is being rerouted to the depleted portions of the pit to allow access to this reserve.

The material in the Airport Pit is very high-quality aggregate. Minor amounts have been removed recently but it has not been a major source because it is on federal land and there are reports that live shells, leftover from the military days, were found in one of the old pit areas recently.

The Mile 4 pit has been in use for many years and portions have been rehabilitated. It was a source of gravel for recent airport repairs. The Town is currently using stockpiles of sand left after screening for stone was completed.

Material from the Northern Studies Centre deposit, which is actually 1.5 km east of the Centre, was also used in the airport repairs. The pit face shows 4 m of gravel with a high crushable content. The deposit continues to the southeast of the pit. Backhoe pits in the unopened portion of this deposit revealed 2 to 2.5 m of coarse gravel (Fig. GS-27-3) with permafrost at the base. This deposit contains enough reserves for several major construction projects in the future.

Several inactive deposits were examined. Of these, the Twin Lakes deposit contains a large reserve of coarse material that would be suitable for rip-rap. The area behind the Gun Club had been previously tested and contains a large reserve of material suitable for traffic gravel. Areas southeast of Halfway Point and on both sides of Bird Cove have reserves of good quality gravel and near-surface limestone, however these areas are heavily used by the tourist industry. The deposit at Isabelle Lake is also an excellent source of aggregate; however the area is important recreationally to the Town. These areas were not tested but existing pits were sampled.

RURAL MUNICIPALITY OF GRANDVIEW

The R.M. of Grandview lies in the valley between Riding Mountain and Duck Mountain in twp. 23 to 27 and rge. 23 to 25, W prin. mer. (Fig. GS-27-4). The area is primarily agricultural although tourism is also economically important due to the proximity of Duck Mountain Provincial Park and Riding Mountain National Park. Highway 5, Provincial Road 366 and section roads give good access to most of the municipality.

Gartner Lee Associates (1978) originally mapped the area as part of a regional aggregate study carried out for the Department of Energy and Mines. The Gartner Lee study is now more than 20 years old but the Department has been updating the aggregate maps on a municipality by municipality basis, usually as required for inclusion in municipal development plans but also as other needs arise. The R.M. of Grandview was selected for remapping this year as the municipality has initiated a development plan and current aggregate data is needed for the plan.

Geology

The R.M. is underlain by Cretaceous shale of the Pierre Formation but no shale is used as aggregate in the municipality.

The glacial history is outlined by Klassen (1979). Late in the Wisconsinan, ice flowing from the north deposited till of the Zelena Formation across the area. This ice sheet stagnated, resulting in the hummocky till deposits found on



Figure GS-27-3: Coarse gravel, Northern Studies Centre deposit.

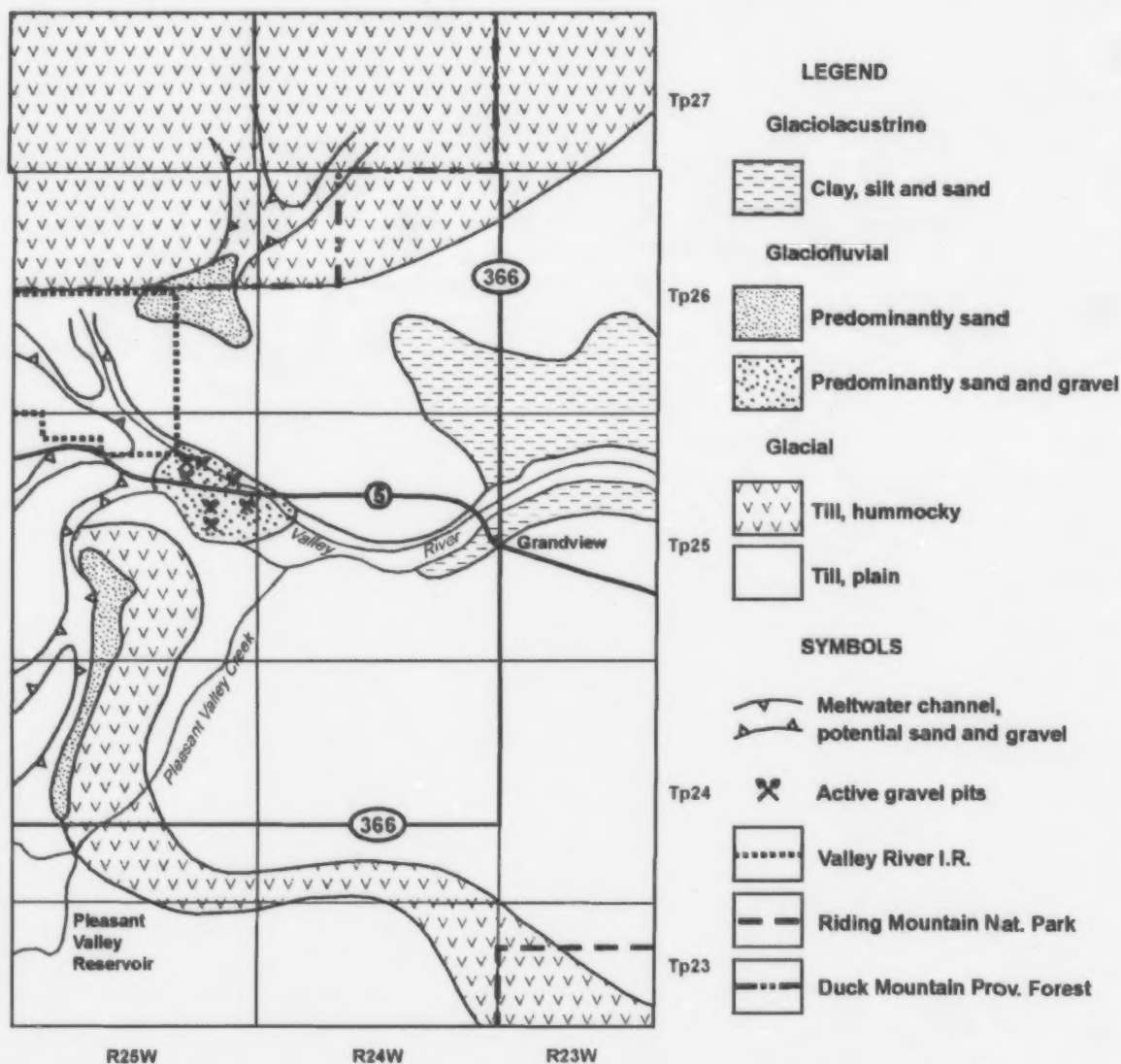


Figure GS-27-4: Location map of the Rural Municipality of Grandview, showing areas of aggregate potential (after Klassen, 1979).

Duck and Riding mountains. The Valley River sublobe, an offshoot of the active ice sheet in the Manitoba Interlake, then flowed westward up the valley between the two mountains, depositing the silty Arran till. The Petlura end moraine marks the west and southern extent of this ice advance. As the Valley River sublobe receded, meltwater ponded on the mountains and flowed downslope, creating meltwater channels and depositing the fan and channel aggregate deposits.

Aggregate Inventory

As with the Churchill area, the aggregate inventory was carried out in two stages; office compilation followed by field-work. Previously mapped deposits were transferred onto 1:20 000 township photomosaics (1991 orthophotos). The township mosaics were used as a base on which to compile aggregate information from several sources:

- Active pit locations – Mines Branch quarry database
- Quarry lease and withdrawn locations – Mines Branch plat books
- Crown versus private ownership – Manitoba Crown Lands Branch database
- Pit and sample locations – Department of Highways block files
- Water-well records – Manitoba Conservation (GWDriII)

Pits, roadcuts and natural exposures were examined during the first part of the field examination. Pits were examined for type

of material, degree of depletion and active/inactive/depleted status. Unopened portions of deposits were inspected and land uses that would limit aggregate extraction noted.

Aggregate samples were processed in two stages. In the field, samples that weighed between 75 and 100 kg were passed through 6-inch (15.2 cm), 3-inch (7.5 cm), 1½-inch (3.8 cm) and ¾-inch (1.9 cm) screens. The weights of the 3-, 1½-, ¾- and less than ¾-inch fractions were recorded. In addition, the relative abundance of less than 6-inch material, as well as deleterious material (e.g., shale, concretions), was noted. Pebble counts on the 1½- to 3-inch fraction were done in the field. A representative sample of the less than ¾-inch fraction was taken for processing by the Material and Research Branch of the Department of Transportation and Government Services, under the terms of the cooperative agreement initiated in 1998.

Aggregate Deposits

The aggregate deposits are of three main types: end moraine, fan and meltwater channel deposits.

End moraine

The western terminus of the Petlura end moraine, locally known as Rose Ridge, is a north-trending ridge in twp. 24 and 25, rge. 25, W prin. mer. It is about 10 km long, 1 km wide and 15 to 30 m high. There are no gravel pits in this feature. The material exposed in ditch sections is crossbedded, medium to fine sand although Klassen reports silt and gravel are also constituents of this part of the moraine (Klassen, 1979). The ridge was drilled by Prairie Farm Rehabilitation Administration (P.F.R.A.) and found to be an excellent source of groundwater. The aquifer contains more than enough water to supply the town of Grandview but has not been exploited due to the cost of piping the water to the town.

Fans

There is one major fan deposit located in twp. 26, rge. 25, W prin. mer. The deposit is primarily pebbly sand and in the past minor amounts of material have been removed for local use. Along the northwestern edge of the deposit the material is medium to coarse sand, blown into dunes. There is pebble gravel at the base but the depth of the overlying sand makes it uneconomic as an aggregate source.

Meltwater channel deposits

There are several meltwater streams that flowed off the mountains; the largest meltwater channels are those that now contain Valley River and Pleasant Valley, Bear and Silver creeks. All have potential for gravel deposits along their length but it is the Valley River channel that contains the only large deposits in the municipality.

While there are small deposits and old pits all along the Valley River channel through the municipality, the main deposit occurs in twp. 25, rge. 25, W prin. mer. This deposit is up to 2.5 km long and about 1.5 km wide. It is bisected by Valley River and much of the deposit is sterilized by Highway 5 and farmsteads. This deposit was active in 1978 when Gartner Lee carried out their study and it is still the major source of aggregate for the municipality in 2001. There are seven active pits and several old pits that either have been abandoned or are being used for minor local use. All the aggregate is privately owned and the pits are used by either the R.M. or local gravel contractors, under agreement with the landowner.

The deposit is a series of linear gravel ridges with intervening areas of sand or pebble gravel. The ridges are 3 to 5 m high with undulating surfaces. The aggregate is generally sandy, coarse pebble gravel with a good crushable content. The amount of sand varies along the length and occasionally across the width of each ridge. Pebble lithology averages 75% Paleozoic and 25% Precambrian. Ironstone concretions, eroded from shale bedrock, make up most of the deleterious content. Despite the presence of the concretions, there is virtually no shale in the sand and gravel. The aggregate overlies stony clay in most places although till was noted occasionally at the base of some pits.

AREAS OF SPECIAL INTEREST

Areas of Special Interest (ASIs) are parcels of land put forward as candidate sites for Manitoba's Protected Areas Initiative. Under this initiative, representative portions of each of Manitoba's natural regions are set aside for biodiversity protection; mining (including aggregate extraction), forestry and hydro development are excluded activities. Eleven candidate areas required site inspection this summer.

Six of the ASIs have low to moderate economic potential for aggregate extraction because of high sand content, previous depletion or difficulty of haulage from the deposit.

Two ASIs contain Precambrian outcrops that are suitable for aggregate and have good road access. There are quarry leases in one of these sites. These two ASIs are several square kilometres and the portions with high quarry potential are relatively small.

There are three ASIs with high aggregate potential. Horseshoe Ridge ASI in the Interlake, has both high-quality gravel

and near-surface bedrock. The gravel is in a large esker and a small beach deposit. Both deposits have active pits. The unopened portion of the esker is under quarry lease. The bedrock, of the Paleozoic Stony Mountain Formation, is not road accessible and has no quarries opened in it. Shoal Lake ASI has an active gravel pit in a small beach deposit. The size of the aggregate area in relation to the total size of the ASI is very small. The Rivers ASI is a quarter section adjacent to the Rivers Provincial Park. The parcel is underlain by a good-quality gravel deposit. The vegetation is a remnant of mixed grass prairie. The site is on one of the few lakes in the area and is used by campers. As the land has both mineral and environmental values, all stakeholders should have an opportunity to comment before a final disposition is made.

ACKNOWLEDGMENTS

The Churchill study benefited greatly from the assistance of the following people: Irv Hiller, Department of Transportation and Government Services, whose experience in aggregate testing was invaluable and whose cooking skills made the stay a pleasure; Merv Walkoski, who provided backhoe services and shared his extensive knowledge of the aggregate deposits around Churchill; Roy Bukowski, Manitoba Hydro, who generously provided airphotos and the biophysical map; and Kyle Canning, who provided field assistance and geographic information system (GIS) expertise.

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SUMMARY

Manitoba's Mineral Resources Division has been storing Precambrian drill core, obtained primarily from exploration drilling, since the early 1970s. Since that time, the Manitoba government has managed to create a substantial repository of drill core at five locations throughout the province. From 1984 to 1989, the Canada-Manitoba Mineral Development Agreement provided substantial funding to expand Manitoba's core library facilities. Since the early 1990s, the core libraries have been run on a care-and-maintenance basis. However, exploration companies continued to deliver drill core to various libraries on a sporadic basis. Due to the lack of funding, core library inventories have not been kept up to date.

In 2001, funding became available to better organize recent drill core additions and to update all core library inventories. Drill core stored at the Centennial compound near Flin Flon was reorganized and inventoried for the first time. The department is also creating a new database of all drill core holdings within the province's libraries.

INTRODUCTION AND HISTORY

The Manitoba Mineral Resources Division considered the archiving of exploration drill core to be a valuable data source that can be utilized by explorationists and researchers. For this reason, the province has retrieved and stored Precambrian drill core since the early 1970s. The construction of core sheds at The Pas (1972), Thompson (1973) and Lynn Lake (1974) provided storage space that enabled a concerted effort toward core collection. The acquisition of storage space in Winnipeg in 1980 for drill core from southeastern Manitoba meant that there was a core storage facility for drill core collected and donated by companies carrying out drill programs in the major greenstone belts of Manitoba.

Precambrian drill core collection has been the responsibility of various Manitoba Industry, Trade and Mines (formerly Manitoba Energy and Mines) personnel. Mines Branch staff administered core collection, or exploration companies delivered core to storage facilities. By the end of 1982, 89 000 m of drill core had been collected. Due to staff shortages during the 1970s, much of this core was not properly inventoried, nor was it stored in an organized manner.

In 1984, the governments of Canada and Manitoba embarked on the Canada-Manitoba Mineral Development Agreement (MDA). This five-year agreement allotted \$24.7 million toward activities that were key to strengthening Manitoba's mineral industry. During the term of the agreement, \$631 000 was spent on capital and operating costs of Manitoba's Precambrian Drill Core Libraries Program. This funding allowed for the expansion of all northern core storage facilities, as well as better documentation and organization of inventories. Once the library expansion projects were completed, the four libraries had a combined storage capacity of approximately 333 000 m of core. Nearly 80 000 m of core were collected and added to the libraries, and about 58 000 m were discarded during the period of the MDA. The libraries contained nearly 180 000 m of core, representing about 54% of total capacity, at the end of the MDA in 1989 (Prouse, 1989).

With the expiry of the MDA, funding for programs related to the core libraries was greatly reduced. Since approximately 1992, the core libraries have been run on a care-and-maintenance basis. Core retrievals by government personnel have been very limited, but exploration companies have continued to deliver core to the libraries.

In 1989, a new regional office was opened in Flin Flon. In 1993, the establishment of an expediting camp at the former Centennial mine site near Bakers Narrows provided secure outside storage for drill core from the Flin Flon area. Since that time, thousands of metres of drill core have been donated for storage by various companies. Drill core at the Centennial site was not included in the provincial libraries inventory.

In June 2001, it was estimated that the department's core library facilities contained approximately 242 000 m of Precambrian drill core. This figure includes about 15 500 m of Precambrian core from various exploration projects stored at the Midland rock lab in Winnipeg. This estimate does not include the substantial holdings at the Centennial site.

2001 INVENTORY UPDATING PROGRAM

In the spring of 2001, funds were made available to organize and update drill core that had been added to the northern libraries since the early 1990s. As well, preparation began on a new computer database to store key information for each drill-hole stored in Manitoba's core libraries. Presently, Open File Report OF89-4 (Prouse, 1989) is the only published report listing Manitoba's core library holdings. The new database is being prepared by Jim Payne, the Assessment Geologist with Manitoba Industry, Trade and Mines (ITM) in Winnipeg. When completed, the database will provide Internet access to information regarding Manitoba's core libraries inventory. One of the key objectives of creating the new database will be the ability to produce maps illustrating the location of drillholes that are held in Manitoba's core libraries. As of September 2001, the database contained information on approximately 2400 drillholes, and it is estimated that there will be 300 to 400 more

drillholes added to the database as the library inventory updating project progresses.

This past summer, with the assistance of summer students and personnel from the Manitoba Geological Survey's Midland rock lab, recent drillhole contributions were reorganized and inventoried at all of the northern core libraries.

In The Pas, 10 holes drilled by Noranda Exploration from Reed Lake and 13 holes by Manitoba Mineral Resources Ltd. in the Minago River-Moose Lake area were organized and added to the inventory. A total of 36 holes drilled in the Snow Lake area by various junior companies and 10 holes drilled by Homestake Mineral Development Company at Elbow Lake will also be added to the inventory.

In Thompson, drill core placed in recently constructed outside racks was inventoried and new drillholes added to the inventory list. All inventory in the inside storage racks was checked for accuracy with previous listings. Thirteen Cominco drillholes from the Easterville-Lake Winnipegosis area were also added to the inventory list.

In Lynn Lake, 40 drillholes by Aur Resources from the Lynn Lake area were added to the inventory. Another 26 holes drilled by Manitoba Mineral Resources Ltd. in the early 1990s at Farley Lake and in the surrounding area were also added to the listings. The core library yard was cleared of scrub brush to make room for a local contractor to retrieve approximately 900 boxes (representing 20 holes) of drill core from the core storage racks at the Fox mine site. These drillholes are from the surface exploration program carried out by Sherritt Gordon Mines to define the Fox mine deposit in the early 1960s. The core racks at the Fox mine are deteriorating and falling over, and the Fox mine site is gradually being reclaimed. The department felt that the surface drillholes from the Fox deposit are a valuable source of stratigraphic information that should be saved for future research purposes. These drillholes will be added to the Lynn Lake core library inventory in 2002, in the outside storage racks if space permits.

The Centennial core storage compound near Flin Flon has received drill core donations from various companies since the site was erected in the early 1990s. By far the largest contributor to this site has been Hudson Bay Exploration and Development, with drill core coming from various projects in the Flin Flon area. Other large contributions have been made by Cominco and Callinan Mines. Due to the lack of funding and manpower, drill core at the Centennial site was both poorly organized and inventoried. Since its inception, core delivered to Centennial has been stacked on pallets on the ground; as a result, core boxes and piles have been gradually deteriorating due to exposure to the elements. This past summer, all drill core piles were better organized and restacked on new pallets, which were then placed on treated fence posts. This will help to preserve this core until some form of sheltered storage facility can be obtained for this resource. The process of taking inventory at Centennial was partially completed in July. The balance of the inventory was to be documented by early October. The data associated with the drillholes will be obtained from the exploration companies or assessment records and added to the database.

FUTURE PLANS

Since many of the province's northern core libraries are nearly full, there is little space available for new core acquisitions. This is particularly true for the Thompson and Lynn Lake facilities. The department is considering a program to condense drillholes (telescoping), in order to reduce inventories and free up storage capacity. The Lynn Lake and The Pas core libraries contain a number of projects with zone-type drilling, but The Pas facility still has adequate space remaining for additional inventory until telescoping becomes necessary. With the addition of new Fox mine drill core, the Lynn Lake library racks will be close to capacity, so telescoping will become necessary. Although the core racks at the two storage buildings in Thompson are completely full at present, there is less opportunity to reduce holdings by condensing holes at this facility. Consideration is being given to expanding the compound yard at the Thompson site, which may provide space for additional outside storage of some type.

HOW TO USE MANITOBA'S CORE LIBRARIES

All five core libraries have lighted, heated inspection rooms with benches, and most have core splitters. Because the core libraries are not permanently manned, inquiries and requests for access to the northern libraries must be made to:

Dave Prouse, Resident Geologist
Manitoba Geological Survey
Manitoba Industry, Trade and Mines
143 Main Street, Suite 202
Flin Flon, MB R8A 1K2
Phone: (204) 687-1632
Email: dprouse@gov.mb.ca

Access to view core at the Brady Road facility in Winnipeg should be arranged with:

Jim Payne, Assessment Geologist
Mines Branch
Manitoba Industry, Trade and Mines
1395 Ellice Avenue, Suite 360
Winnipeg, MB R3G 3P2
Phone: (204) 945-6535
Email: jpayne@gov.mb.ca

Once permission has been granted to view nonconfidential core in a specific library, arrangements will be made for the user to obtain keys to gain access to that facility. In the case of Thompson, The Pas and Flin Flon, keys can be obtained at the local ITM offices. Keys for access to the Lynn Lake core library will be made available at the local office of Manitoba Conservation.

The master file of drillhole logs, collar locations and assays for nonconfidential drill core holdings in The Pas, Lynn Lake and Flin Flon libraries will be available for inspection at the ITM office in Flin Flon. The corresponding files for core stored in the Thompson and Winnipeg libraries will be available for viewing at the ITM office at those locations.

Viewing, Storage and Sampling Policy

Access to confidential drill core is allowed only with written permission from the company that holds the property. This information must be presented to the Resident Geologist in Flin Flon or the Assessment Geologist in Winnipeg prior to inspection (depending on the core library in question).

Core boxes placed in a library will be managed by ITM personnel. Removal of core boxes from the library premises is not permitted. Users wishing to examine drill core must be prepared to physically handle the core boxes and return them to the racks. Permission is required to sample core contained in any of the province's libraries. Assay results and pulps from these samples must be forwarded if requested. Quartering of previously sampled drill core is not permitted.

Drill Core Acquisition Policies

Manitoba's drill core acquisition policies try to reflect the exploration strategies of the mineral-exploration industry and, as a result, are subject to review as priorities change.

Collection

Since funding for the drill core libraries was greatly reduced after the termination of the MDA, requests for collection of drill core by department staff have had to be turned down, except in rare circumstances. When funding is available for retrievals, a number of factors are considered for precedence. These include 1) location; 2) cost of retrieval; 3) degree of risk to core from vandalism and weather; 4) amount of Precambrian outcropping in the area; and 5) importance of the core in terms of enhancing the understanding of the regional metallogenesis and stratigraphy. If resources allow, core from selected or representative holes will be collected from areas of abundant Precambrian outcrop and/or high drilling density.

For exploration companies or individuals wishing to donate drill core to the libraries, Manitoba Mining Regulation 64/92 allows for expenditures for the transportation of drill core to a departmental core storage facility to be submitted for assessment credit when filing reports of work on a mineral disposition.

Reduction

Where it can be established that information obtained from a group of drillholes located from the same area is redundant, holes or portions of holes that are representative of the subsurface geology and/or mineralization will be stored and the remaining material discarded. This will ensure adequate future storage capacity.

ACKNOWLEDGMENTS

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SUMMARY

Geoscience Information Services Section has worked extensively on digital conversion of both bedrock and surficial geology maps. Geographic information system (GIS) and data-management support has been given to the Western Superior NATMAP project, the Flin Flon Targeted Geoscience Initiative and the EXGIS southeast Manitoba digital geological data compilation. New presentations were developed for the Internet map server system on the departmental Web site.

INTRODUCTION

The Geoscience Information Services Section (GISS) of the Manitoba Geological Survey is responsible for all GIS, CAD, graphic arts and database work in the Survey. The section also acts as a resource of expertise on computer hardware, software and systems for the Department. Internet map publishing and website database publishing fall under GISS as well.

SURFICIAL GEOLOGY COMPILATION MAPS

As part of the ongoing program to convert existing paper maps to electronic form and, where possible, to update and upgrade their content, GISS has undertaken conversion of existing 1:250 000 scale surficial geology maps to digital form. These maps will be edge-matched and reclassified according to a common legend. The objectives of this project include:

- a digital geology base for use in the production of a three-dimensional modeling project (Matile et al., GS-23, this volume);
- production of a digital 1:250 000 scale surficial geology base to be used with the GIS Map Gallery (see below); and
- production of a seamless 1:250 000 scale surficial geology base with a common legend, to be used in the construction of an updated 1:1 000 000 scale *Surficial Geology of Manitoba* map to replace the 20 year old Map 81-1 (Manitoba Mineral Resources Division, 1981).

The compilation incorporates all relevant Manitoba Geological Survey (MGS) and Geological Survey of Canada (GSC) surficial geology maps. The current status of this project is shown in Figure GS-29-1.

MAP PRODUCTION TECHNIQUES

The Manitoba Geological Survey is in the process of modernizing map production and printing. While all map construction and layout have been done with digital technology for several years, there has been a reliance on conventional printing-press methods for publishing full-colour maps. Acquisition of a high-speed inkjet printer allows for rapid in-house printing of colour maps using GIS technology. Currently we do not use 'print on demand', where a client waits for a map to print, but rather use short-run inkjet printing to maintain a small stock of all maps.

The first test of this new production capability was the layout and printing of 15 full-colour preliminary maps for the geological compilation of the Thompson Nickel Belt, produced by the Thompson Nickel Belt Geology Working Group (2001a-o). Production of this number of colour maps in the available time would not have been possible using previous software and printing processes.

Geographic information system software used in map production has been upgraded to the latest ArcGIS® 8.1 product from ESRI Inc. This allows improvement in the quality of map layout and reduction in production time.

BEDROCK GEOLOGY COMPILATION MAP SERIES (BGCMS)

The Bedrock Geology Compilation Map Series is an ongoing program of 1:250 000 scale bedrock geological compilation presented as annotated maps with marginal notes. Previous production relied on manual drafting and conventional press printing of colour maps. The production of these maps has been changed to GIS technology and printing will now be done in house (see above). All previously produced maps have been converted to digital form; all new maps are completely digital from the start of the compilation process. The current status of the BGCMS project is illustrated in Figure GS-29-2. Work is currently focused on the northern eight sheets in the Cochrane-Seal rivers area. Work is complete on NTS 64N, nearing completion for NTS 64O and well advanced for the remaining six sheets. These maps were modified by D. Schledewitz to update the previous maps (Schledewitz, 1986).

Future directions for the BGCMS program are to:

- complete the Cochrane-Seal rivers project;
- update map 64B, which is currently out of print;
- incorporate the results of new geological compilation projects into 62H, 62I, 52E and 52L;
- incorporate NATMAP Shield Margin Project results into 63J, 63K, 63N and 63O;

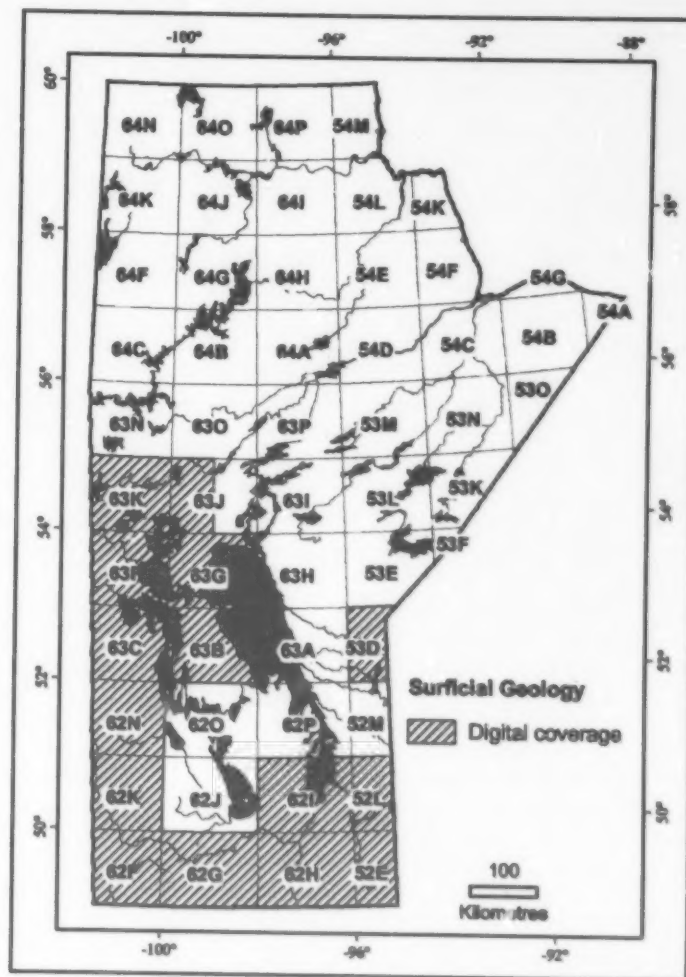


Figure GS-29-1: Current status of the surficial geology digital compilation project.

- add new sheets 63G (currently underway), 63A and 53D;
- incorporate a new revised legend structure into all BGCMS maps; and
- reclassify the digital BGCMS maps for a project to revise the 1:1000 000 scale *Geological Map of Manitoba*.

REGIONAL GEOLOGICAL COMPILATION PROJECTS

In addition to the BGCMS project, GISS is involved in several other map and data compilation projects, including:

- Western Superior NATMAP 1:250 000 and 1:500 000 scale map compilations. MGS produced prototype layouts and symbol sets for the MGS–Ontario Geological Survey–GSC joint project.
- Central Wabigoon geological compilation with T. Corkery.
- EXGIS compilation: a joint MGS–GSC project to produce a digital compilation of all available data for southeastern Manitoba (parts of NTS 62H, 62I, 52E, 52L, 52M and 62P); and
- compilation of kimberlite indicator-mineral data (Fedikow et al., 2001a, b).

GIS MAP GALLERY

The 'GIS Map Gallery', a web-enabled Geographic Information System, has received a positive response over the past year and proven to be a valuable service to our clients. The Map Gallery is currently receiving 600 to 1100 hits per month. The system provides timely and accurate twenty-four hour access to the department's information through an easy-to-use, interactive, information-reference mapping tool. We have continued to develop and enhance the Map Gallery with the addition of the complete mineral-exploration assessment library of reports, which are now available for download in PDF format. Developments for the upcoming year include publication of the 1:250 000 scale bedrock and surficial geological mapping and mineral deposit locations for the province. Petroleum-well locations and associated information relevant to the oil and gas industry are also planned for publication on the GIS Map Gallery.

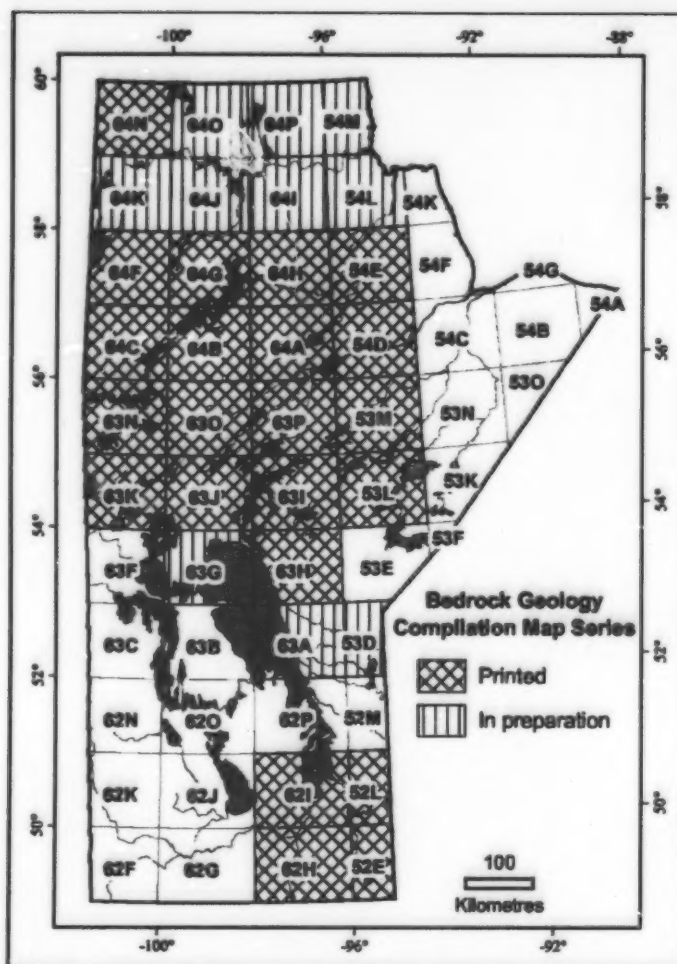


Figure GS-29-2: Current status of the Bedrock Geology Compilation Map Series project.

What can you do at the GIS Map Gallery? Prospectors, geologists, mining company staff and other interested stakeholders are now able to:

- see where mineral dispositions are located;
- investigate the geological setting and see what infrastructure exists in their area of interest;
- determine areas that are restricted in terms of staking and exploration;
- find out who holds what ground;
- find out what ground is available for staking in their area of interest; and
- find out where recent staking has taken place and what work has been done in the area.

The GIS Map Gallery is the access point for information on mineral claims, assessment files and geological databases. It can be found at <http://www.gov.mb.ca/em/geoscience/gis/gis-index.html>.

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